"A Study of the Magnesium Content of Plant Material."

Thesis submitted to the University of Edinburgh
for the degree of Ph.D. by E. Sheila R. McCallum, B.Sc.

Contents.

INTRODUCTION

The chief object of this investigation was in essence an indirect attack on the problem of "Grass Tetany", which has been known as a disease among sheep and cattle for many years. It was first reported and named by Sjollema and Seekles (1920) (54) but it has only recently become so widespread as to be regarded as of serious economic importance.

The disease occurs in cattle of both sexes and all ages at various seasons of the year, at grass or inside on stall rations, and also in sheep. The most common type occurs in dairy herds within a few days of the cows being turned out to grass after spending winter indoors. The disease is characterised by its sudden onset, the symptoms being loss of appetite, hyperirritability which may be followed by convulsive tetany and death.

One factor which is common to every case of the disease is the low level of magnesium in the blood. The normal level is 3 mg. per 100 ml. serum but according to Stewart (57) it may fall as low as 1 mg/ml. in cases of tetany. This state is known as hypomagnesaemia and may occur without clinical symptoms of tetany. In fact Stewart (57) reports that although only a few animals in a herd may succumb to tetany, generally the whole herd shows low blood magnesium. In some cases the disease can be cured by injections of calcium and magnesium or of magnesium alone, even after the symptoms of tetany have appeared.

The/

The direct cause of the disease is not known. Attempts have been made to correlate the level of blood magnesium with magnesium in the diet and there is evidence to show that the feeding of MgO or Mg rich supplements does alleviate and in some cases reduce the fall of serum magnesium whilst experiments with cattle (Stewart[57]) have shown that low blood-magnesium can be induced by feeding low Mg diet. Bartlett[4] et al however report that hypomagnesaemia with or without clinical symptoms may occur on a grass diet, containing adequate magnesium by some accepted standards.

In spite of the fact that pasture usually provides a higher intake of magnesium, dairy cows are much less prone to hypomagnesaemia on a hay and cereal stall diet than on pasture, and the disorder commonly occurs within a few days of the animals being turned out to grass. Workers in New Zealand (————) have found cases of hypomagnesaemia occurring on pastures containing anything from 0.2 - 0.6% of magnesium. In view of this evidence, Bartlett et al suggest that tetany may be caused by a physiological dysfunction rather than a direct nutritional deficiency of magnesium. Brouwer (1952)[8] has already suggested that the relative proportions of the various base-forming and acid-forming elements in the diet may influence the blood serum-magnesium level, and has shown that in particular a high potassium level in the diet in relation to the magnesium may result in tetany. Experiments with fertiliser treatment of grasses (Bartlett et al.) have shown that on pastures treated with heavy dressings of/

of potassium sulphate, hypomagnesaemia and even tetany may occur, but only where the clover content of the sward is low.

Alten et al[2] on the other hand state that they have fed large doses of potassium salts to cattle along with the daily fodder without any appearance ot tetany, and argue that potassium is unlikely to be a contributory factor in tetany since pastures in Germany where the potassium content of the soil is very high do not show any greater incidence of tetany amongst grazing aminals than do normal pastures.

Bartlett and co-workers also report a linkage between grass tetany and heavy fertiliser dressings of ammonium sulphate. It was thought that this might be due to the presence of large amounts of ammonium salts in the diet causing the NH_3 in the blood to rise above the toxicity level, but experiments with cattle showed that by feeding ammonium salts orally, it is possible to raise the blood NH_3 to 2 mg%-within $\frac{1}{2}$ mg% of the critical level - without the appearance of hypomagnesaemia.

The above evidence shows that the problem is extremely complex. The main difficulty in correlating the magnesium in the diet and the occurrence of hypomagnesaemia is the lack of knowledge about the magnesium content of foods in general. For many years analyses of grasses and hays have been carried out for the main elements N, P and K, but very little has been done on magnesium, although it is known that the magnesium content of herbage varies during the season and is lowest/

lowest in the spring (27,50) when tetany is most prevalent. Even Fagan in Wales who carried out so many experiments on grasses and clovers and estimated protein, fibre, P_2O_5 and CaO, makes no mention of magnesium. Consequently it was decided that it would be of value to investigate the seasonal variation in the magnesium content of herbage and the effect of various fertilisers, including $MgSO_4$ on that variation.

Review of Literature

Although until recently little work had been done on magnesium in herbage, several workers in America, Germany, Holland and in this country have studied the role played by magnesium in other plants. Interest in the subject was aroused early in the century by a disease which appeared in cereals, and was called in Holland "Hooghalense Ziekte". It occurred mainly on acid soils where there was a high degree of leaching and was characterised by intervenal chlorosis which started at the edge of the leaf and worked toward the centre. Eventually the whole leaf yellowed and withered. In severe cases, the plants were stunted and the yield was seriously reduced. The disease also appeared infruit trees, and it was because of the economic importance that the subject received so much attention. Although most of the early work was concerned with cereals, legumes and fruit trees, it is of interest and importance with regard to herbage in that it throws considerable light on the question of the role of magnesium in plants and its relationship to other elements.

The connection between magnesium and chlorosis was first shown by **Mameli** (37) who found that the ash of green plants contained a higher percentage of magnesium thandid the ash of chlorotic plants. Further, the amount of colouring matter extracted from certain plants was dependent on the amount of magnesium supplied in the nutrient solution. This relationship was supported by Longnecker (35) who found a significant/

significant correlation between the concentrations of chlorophyll and magnesium in the leaves of corn. From these experiments, it was deduced that magnesium was necessary for the formation of chlorophyll. In fact it comprises 2.9% of the chlorophyll molecule. In magnesium-deficient chlorotic plants, photosynthesis cannot take place and the whole mechanism of the plant is slowed down.

Although the chlorophyll magnesium has been shown by Javillier and Goudehaux (30), and, more recently, Scharrer & Schreiber (51) to comprise only a small fraction (10%) of the total leaf magnesium, Garner et al (21) have found that in order to prevent breakdown of chlorophyll, the total magnesium content of the leaf must be several times the amount present in the chlorophyll. This would seem to suggest that the main function of magnesium within the plant in in relation to the chlorophyll.

Other authors (25, 51) have found that deficiency of magnesium causes a loss in the lower leaves of the plant of xanthophyll and carotene, in addition to the chlorophyll loss.

Neales (41) has recently extracted the colouring matter from green leaves of perennial ryegrass and white clover and estimated the magnesium content of the various fractions. Apart from the chlorophyll-magnesium and the magnesium present in the residual colourless matter, he found that a certain percentage existed which was probably soluble in water. This supports Cooper's earlier observations (12) that the bulk of the magnesium is apparently combined with protoplasm and present/

present as free inorganic salts in the cell sap.

It would appear from the work published so far that although the main role of magnesium within the plant is in photosynthesis, it does however perform other functions. In view of the relationships which have been found to exist between magnesium and other elements by means of excess or deficiency of these elements in nutrient solutions or soils, various theories have been proposed as to the nature of these functions, but the evidence is not sufficient to draw any conclusions and the subject is still a matter of controversy.

One of the earliest suggestions was that magnesium was related to phosphorus in the plant and that it might act as a carrier of phosphate to the seed where the phosphorus is necessary to form **lecithins** and lipoids, and for the formation of nucleoproteins. Since magnesium salts undergo dissociation and hydrolysis easily and secondary magnesium phosphate is very soluble in water and would be easily transported through plants, this suggestion is reasonable. Evidence on the subject however is conflicting.

As early as 1903, Loew (34) reported that the percentage of magnesium in oily seeds as compared to starchy seeds was unusually high. Shortly afterwards Willstätter (65) found that the nutritive tissues of cereal seeds contained more magnesium than the green assimilating parts of the plant, and that during ripening of the seed the magnesium and phosphorus contents increased. Bernadini (6) showed that absorption of phosphorus by plants and its transportation within/

within the plants occurred most easily in plants with ripe and waxy seeds.

This relationship between magnesium and phosphorus in the seed has been supported by more recent evidence (20a, 49) that in fruit trees, magnesium tends to move from old leave to the fruit rather than to the newly developed leaves. In fact Fudge found that by autumn chlorosis had developed in the leaves and they dropped from the trees.

Webb, Ohlrogge and Barber (64) have shown that in soybeans phosphorus also moves from the stem to the seed as the plant matures and that this occurs more readily in normal plants than in magnesium-deficient ones. In tomato plants grown on phosphorus-deficient media, Eckerson (15) found that chloroplasts began to disintegrate at first in the stem and lower leaves and later in the upper leaves. Addition of phosphorus to the nutrient medium during the first stage of the breakdown process made recovery possible.

It would seem from these results that magnesium and phosphorus are very closely related. Contradictory evidence is reported by Daniels (13) who calculated ratios between phosphorus and magnesium in grasses and legumes but could find no positive correlation between the two and Willis, Pilland and Gay (68) who were unable to find any relationship between magnesium deficiency and phosphorus deficiency. Other authors (62b) could not find any significant effect of magnesium on the distribution of phosphorus in avocados. It is however rather difficult to compare directly results such

as/

as these obtained from experiments carried out under different conditions and on different plants.

Following this suggested action of magnesium as a phosphate carrier, it might be supposed that there would be a relationship between the available magnesium in soils and the phosphorus content of the plant, and indeed various workers (Obst in Germany (43), Kellogg in America (31), Bartholomew (3), Krackenberger and Peterson (33), and more recently, Mulder (40)) have found that the application of magnesium fertilisers to soils increased the uptake of phosphorus by plants. Truog and Goates (60), in experiments with peas, found moreover that as the supply of available magnesium was increased, the phosphorus content of the plant increased more than it did with increase of available phosphorus, but as the pH altered during the experiment, the interpretation of their results is open to some doubt.

Other authors (Webb et al (64) and Wallace and Ashcroft (62b)) have been unable to find any direct correlation between the available soil magnesium and the phosphorus uptake. The latter workers did find however that a relationship occurred in crops with low magnesium requirements and in soils with a high level of available phosphorus.

The conflicting nature of the evidence on this aspect seems to suggest that the effect of available magnesium in the soil on the phosphorus content of plants will depend on the type of plant, the type of soil on which it is grown and the other available nutrients in the soil.

The/

The relationship of magnesium to other elements, in particular calcium, potassium and nitrogen, has also been studied. Most of the results reported in the literature point to the fact that potassium and magnesium ions are antagonistic towards one another.

Boynton and Compton (76) found that in apple orchards showing magnesium deficiency, the leaf potassium tends to be abnormally high, even though the amount of replaceable potassium in the soil was low, and Wallace et al (62c) have reported that magnesium deficiency symptoms appeared on potatoes grown on soils where potassium fertilisers had been applied. The deficiency was less prevalent where farmyard manure had been used. Prince, Zimmerman and Bear (47) go as far as to say that the amount of available potassium is the most important single factor influencing the uptake of magnesium and other authors (28, 63a & b), working with various plants found that the uptake of magnesium bore a direct relationship to the Mg:K ratio in the soil.

Other authors have reported that the amount of available calcium is important. Shive[53] studying growth of wheat plants at various ratios of calcium, magnesium and potassium, found that for any given set of salt proportions, the total concentration of the medium determined the growth of the plants. For any single ratio of Mg:Ca, for example, the relationship was not always clear. Cooper[12] has reported that many plants tend to absorb the relatively stronger cations selectively and that the amounts of magnesium in most/

most plants were generally significantly lower than those of potassium or calcium. Zimmerman (70) showed that at higher levels of fertility, these cation ratios are important and that an excess of calcium or potassium can be harmful unless accompanied by adequate magnesium. At low fertility levels, however, plant uptake of magnesium is more closely related to the supplies of available magnesium in the soil.

This theory of the importance of ion ratios has been extended to the Mg:P relationship. Truog suggested (60) that a proper balance between calcium and magnesium rather than a supply of magnesium was necessary for efficient utilisation of phosphorus, and Hunter (28) has reported that in experiments with alfalfa in pot cultures, as the Ca:Mg ratio in soils decreased, the phosphorus content of the plant increased, provided that the supply of magnesium exceeded that of calcium. When the available calcium was greater than the magnesium, increase of the latter had no effect on the phosphorus content of the plant.

Other authors have studied the effect of nitrogenous fertilisers on the uptake of magnesium by plants. Obenshain (42) found that the application of nitrogenous fertilisers to corn increased the amount of magnesium in the tissues and Hoblyn (26) found that leaf scorch in magnesium deficient fruit trees was reduced by similar applications. Boynton and Compton (7a) obtained a positive correlation between leaf nitrogen and leaf magnesium in fruit trees differentially fertilised with nitrogen and Olson and Bledsoe (44) noted a nearly constant relationship between nitrogen and magnesium in/

in cotton.

Conversely, work on legumes has shown that treatment of soils with magnesium increases the fixation of nitrogen by these plants. Albrecht (1) found that in the absence of magnesium, fixation was negligible unless extra calcium was available. As more magnesium was added, fixation increased. He suggested that nodule bacteria required a high level of soil fertility particularly in the form of calcium and magnesium, to function properly. Magnesium also seemed to assist in the release of calcium which was absorbed by the plant with resulting increase of nitrogen-fixation. Graham (24) showed that magnesium stimulated bacterial activity in soybeans to a much greater degree than did calcium compounds, thus increasing nitrogen fixation.

The problem of magnesium nutrition in plants in extremely complex and seems to depend on several factors, the most important being the amount of available magnesium in the soil.

As tetany has become more prevalent, interest in the herbage side of the subject has increased and in recent years a number of results have been published by Stewart, Stewart & Holmes, and Reith. Fagan and colleagues (17) drew attention to the fact that the composition of grass changed during the season, the nutritive value increasing until the grass reached the hay stage and then deteriorating rapidly. They found that the mineral content varied from leaf to stem so that the mineral content of the whole plant would depend to a large/

large extent on the proportion of leaf to stem which, also varied during the season. Although their estimations of mineral content were confined to P_2O_5 and CaO, it seems reasonable to suppose that the magnesium content would also vary during the season, and indeed Stewart (57) Stewart and Holmes (58) and Reith (50) have confirmed that this is the case. The magnesium content of pastures tends to be low in the spring and to increase during the season. Reith (50) reports that on soils which are low in both pH and available magnesium, the magnesium content of herbage under a system of two to four weekly sampling varied considerably from its low spring value to a fairly constant value from July onwards. He makes the reservation, however, that the results obtained from pastures may depend to a large extent on the sampling technique used and on the frequency of cutting. This latter factor was discussed earlier by Evans (16) who showed the effect of different grazing systems on the mineral content of grass, and Fagan (17) who showed that the more often a grass is cut, the more leafy it will tend to become with a consequent alteration in mineral content.

There is evidence that the magnesium content of a pasture will depend also on the proportion of the various species present. Fagan suggested that different species of grass would have different mineral contents, and Williams and Evans (66) found that there was a considerable difference between grass and clovers, the latter being richer. More recently Thomas et al (59) in Newcastle have investigated magnesium contents/

contents and have reported that weeds and clover are much richer than grasses, and consequently that pastures containing a high proportion of these species will tend to have a high magnesium content.

Ways of increasing the magnesium content by application of fertilisers have been studied. Since low magnesium herbage generally occurs on acid soils where the nutrients have been leached out, the importance of increasing the soil pH has been emphasised. (Jacob (29), Scharrer & Schreiber (51) and Mulder (40)). Mulder has recently suggested that apart from the effect of leaching, low pH actually hinders the uptake of magnesium by preventing complete development of the root system in plants. Application of lime or limestone however to soils of this type serves only to aggravate the deficiency of magnesium by upsetting the Ca:Mg ratio. Mulder (40) and Stewart (57a) Stewart & Holmes (58) have found that applications of lime or limestones rich in magnesium, such as burnt magnesium lime or dolomitic limestone, in addition to increasing the pH, will increase the available magnesium in the soil and hence the magnesium uptake by crops.

Reith & Williams (50b) have found that while burnt magnesian lime markedly increased the magnesium content of crops, low grade magnesian limestone had little effect. More recently Reith reports (50a) that application of magnesium limestone at rates varying from 20 to 40 cwts./acre increased the magnesium content of mixed herbage throughout the growing season.

On/

On soils where the pH is neutral, the magnesium content may be increased by application of magnesium sulphate, kieserite or potassium magnesium sulphate and such treatment is recommended by Jacob (29), Wheeler and Hartwell (64a) and Mulder (40). Moser (39) also reports that application of pure magnesite increased the available magnesium in the soil.

Other work on magnesium fertilisers has been done on cereals and roots. Reith (50a) has found that application of limes rich in magnesia increased the magnesium content of the tops of mangolds, fodder beet and turnips and of the leaves of kale. The magnesium content of the roots and the stems were practically unaffected.

Certain other fertilisers although devoid of magnesium seem to affect the uptake by plants. Stewart & Holmes (58) studied the effect of nitrogenous fertilisers on herbage and showed that their application tends to increase the magnesium content. Potassium supplements, on the other hand, have a depressing effect on the magnesium content. These results agree with the earlier work on other plants. Mulder (40) obtained similar results with certain nitrogenous fertilisers but observed that different forms of nitrogen appeared to have different effects. Fertilisers containing nitrate ions e.g. $NaNO_3$ tended to increase the magnesium content while those containing ammonium ions e.g. $(NH_4)_2SO_4$ actually tended to encourage magnesium deficiency on soils already low in magnesium.

It would seem that one of the most important factors determining/

determining the uptake of magnesium by plants is the ratio of the various cations and anions in the soil. Alteration of one of the major nutrients by application of fertilisers or by natural influences such as leaching by rain, will upset the balance of the others and so alter the uptake. Thomas et al found in their studies on hay that the application of incomplete fertilisers depressed the magnesium content. Although interest in this aspect of the problem has been aroused in recent years, much work remains to be done, and it was with the intention of investigating further some of these factors with particular reference to conditions in the East of Scotland that the present work was undertaken.

Toxic effect of Mg.

Finally there remains the question of excess of magnesium. At the beginning of the century it was suggested that excess of magnesium in the soil had a toxic effect on plants. If the ratio of Ca:Mg was less than 1, this toxic influence would arise.

Follet Smith (18) stated that this effect was due to the presence of excess soluble salts of magnesium and possibly sodium. Later Smith et al(55) showed that Arizona soils containing excess magnesium are unproductive because of the physical properties of the clay. In this country, it is rare to find the magnesium in soil exceeding the calcium but it has been observed that excessive applications of burnt lime rich in Mg lead to sterility in the soil and it has been suggested that/

that the toxic factor is probably high alkalinity since MgO resits carbonation longer than CaO and is sufficiently soluble to maintain a fairly high pH in soil.

Object of Investigations

A. The seasonal variation in the Magnesium content of various species of grass and clover cut at monthly intervals, and the effect of Nitrogenous fertilisers thereon.

B. The seasonal variation in the Magnesium content of ryegrass grown for hay and the effect of Magnesium fertilisers thereon.

C. The seasonal variation in the magnesium content of herbage grown for hay and dried grass and the effect of magnesium and potassium salts thereon.

D. The magnesium content of turnips and kale and the effect of magnesium-potassium sulphate thereon.

Sites available.

A. Boghall: species of grass and clover.

Samples of various species of grass and clover were taken from plots laid down under carefully controlled conditions by the Advisory Botany Department at Boghall Farm to find the effect of nitrogenous fertilisers on the proportions of various strains of grass and clover in a sward. The species sown were Cocksfoot with White Clover, Perennial ryegrass with White Clover and Italian ryegrass with red clover. The strains chosen for chemical analysis were Danish cocksfoot and White Clover (A1), Ayrshire ryegrass and White Clover (A2), and Italian ryegrass and Red Clover (A3). The first two pairs/

pairs were sown in control plots and plots treated with nitrochalk and cut at monthly intervals so that the grass never reached maturity. The conditions were therefore almost comparable to those which might be found under grazing: the third pair in plots with light and heavy dressings of nitrochalk cut at six-weekly intervals.

B. Bush: perennial ryegrass.

A specialised experiment consisting of three plots sown with perennial ryegrass was laid down at Bush Estate, each plot was treated with particularly heavy dressings of magnesium salts. The samples were taken monthly throughout the season and the grass was allowed to reach seeding stage before being cut over.

C. Fife and Perthshire: herbage.

Sites were chosen w~~e~~re outbreaks of tetany have been prevalent in recent years and where the soil was suspected to be low in available magnesium. The farms were Downfield farm, Fife and Bankhead farm, Forteviot. 5 x 5 latin square experiments were laid down at each centre showing the effect of potassium and magnesium sulphates on the magnesium content of herbage.

C1. Downfield farm and Bankhead farm (East Bankfield). One field was chosen at each centre where herbage was being grown for hay, and samples taken at monthly intervals until September.

C2. Bankhead farm (New Mill field). This field contained grass/

grass grown for dried grass. It was cut at monthly intervals and sampled approximately a fortnight after cutting.

D. Fife and Perthshire: turnips and kale.

The turnip experiments (D1 and 2) were laid down at Downfield farm and Lower Luthrie farm in the form of 3 x 3 latin squares to show the effect of potassium-magnesium sulphate on the magnesium content of turnips.

The kale experiment (D3) also in the form of a 3 x 3 latin square was laid down at Bankhead farm, Forteviot.

Errors

The errors arising from this type of experiment may be divided into three groups.

a) analytical errors in the laboratory.

b) variations within a sample.

c) field sampling errors.

a) Analytical errors in the laboratory.

25 g. dried grass were weighed out accurately, ashed and extracted and the extract made up to 500 ml. 100 ml. aliquots were analysed separately. The results are shown in Appendix 1a.

b) Variations within a sample.

Samples of grass from several fields were thoroughly mixed and milled and the mixture stored in a large bottle. A series of analyses was carried out using 5 g. portions. Results (Appendix 1b) show the variation which may occur in taking sub-samples from any large sample of herbage.

A 100 g. sample of the mixture was measured out, remilled, thoroughly mixed again and stored in a small bottle. A series of analyses was carried out on 5 g. portions. The results (Appendix 1b) show the variation which may arise in taking a subsample from any small sample of herbage.

To test the recovery of magnesium, four 5 g. portions of mixture 2 were weighed out and ashed and extracts prepared. To each extract was added 0.25 mg Magnesium (added as $MgSO_4.7H_2O$)/

$MgSO_4.7H_2O$), and the analyses were continued as before. A further four extracts were prepared and after precipitation of calcium, 0.25 mg. magnesium was added to each. The results (Appendix 2.) show that recovery was good.

To find the variation in phosphorus content, a series of analyses were carried out on portions of the same grass. The results are shown in Appendix 2.

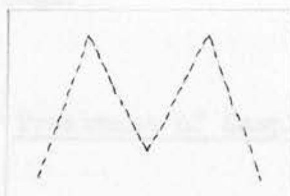
c) Field sampling errors.

The error arising from collection of grass samples from a field is liable to be considerable because of the variation in the grass. To overcome this, the experiments on herbage were laid down either in the form of 5 x 5 latin squares or as randomised blocks. Normally the samples were bulked in the laboratory according to treatment but at least once during the season in each experiment the samples from each plot were analysed separately to give some idea of the variation between plots receiving the same treatment.

Collection of Samples

1. Herbage

The samples were cut with shears at a height of about 1 inch above the soil surface, care being taken to avoid contaimination with soil or faeces. In the latin square experimental plots, the samples were taken from each plot in an 'M' formation, as shown, starting about 1 ft in from the edge of the plot.



The samples were transported to the laboratory in stiff paper bags. Each sample was thoroughly mixed and where necessary, a sub-sample was taken.

Methods of sampling.

(a) Subsampling: Each sample is thoroughly mixed and a subsample taken.

(b) Composite sampling: Each sample from one particular set of treatments e.g. all the A samples or all the B samples, etc., is thoroughly mixed and a subsample taken. The sub-samples are mixed together and from the mixture, a composite sample taken.

2. Turnips and Kale.

Leaf samples were collected from each turnip and kale plant/

plant and transported to the laboratory in bags. Cores were taken from every second turnip in each plot and a 4 inch cross section of stem from every second kale plant. The cores were transported to the laboratory in tins and the stem samples in bags.

3. Soil.

The soil samples were taken from each plot with an auger after the plants had been sampled, and were transported to the laboratory in paper bags.

Treatment of Samples

1. Plant material.

The samples were weighed, dried (herbage, leaves and kale stems at 100°C and turnip cores at 80°C) reweighed, milled and stored in bottles.

2. Soils.

The samples were air-dried on trays. Large stones were removed and the samples ground and returned to the bags.

SECTION II

Chemical Analysis of Samples

1. Plant Material.
2. Soils.

1. Plant Material

a. Determination of Calcium and Magnesium.

In view of the length of the conventional method for determination of calcium and magnesium, it was decided to try to develop a quicker method using a titration with disodium ethylene diamine tetraacetate.

Ethylene diamine tetra-acetic acid is one of the best known of the "complexones" investigated by Schwarzenbach and his coworkers (52). In the form of the disodium salt, it is used as a titrating agent for several metal ions and has been successfully applied to the determination of calcium and magnesium in water. It was thought that this method might be suitable for the determination of these elements in the routine analysis of plant materials.

The method involves two titrations, one for calcium and magnesium together using solochrome black as indicator, and one for calcium using murexide. The solochromeblack forms a red complex with calcium or magnesium ions but reverts to its normal blue colour on displacement from the complex by E.D.T.A. The/

The titration is carried out using an ammonium hydroxide - ammonium chloride buffer at pH 10. In order to obtain the best results, the E.D.T.A. must be added slowly as the end-point is approached.

The murexide (ammonium purpurate) does not react with magnesium. It forms a pink complex with calcium ions and, on displacement by E.D.T.A., reverts to its normal orchid-purple colour. Prior to this titration, the pH is raised to 12 by addition of sodium hydroxide and the best results are obtained when the E.D.T.A. is added as soon as possible after the murexide, and the titration is carried out quickly, for the indicator fades on standing.

The magnesium is found from the difference between the two titrations.

One difficulty in applying this method to extracts of plant ash, is the presence of iron, manganese and phosphate, in amounts sufficient to interfere with one or both of the titrations. Several papers have been published on the subject. Cheng and Bray (9a) removed the iron and manganese by precipitation and, in a later paper, Cheng, Melsted and Bray (9b) described the removal of heavy metal ions by treatment with sodium diethyldithiocarbamate and extraction with isoamyl alcohol and chloroform. Forster (19) also used sodium diethyldithiocarbamate to remove interfering ions but extracted with carbon tetrachloride; calcium was precipitated as oxalate and the magnesium determined in the filtrate. Mason (38) proposed a micromethod for the determination/

determination of small amounts of calcium, in which phosphate was separated by passing the solution through a cation-exchange resin, the cations being subsequently eluted with hydrochloric acid. An anion-exchange resin has been employed by Gehrke, Affsprung and Lee (23) to remove the phosphate, calcium being determined directly in the effluent.

Experimental

Reagents:

1. .018N E.D.T.A.: 8.25 g. E.D.T.A. (B.D.H. Ltd.) dissolved in 46 ml. N sodium hydroxide and made up to approximately 2,500 ml. with CO_2-free water. Standardised by titrating against 20 ml solution 2, 30 ml water, 1 ml solution 3 and 0.2g. solochrome black to a blue end-point.

2. Standard Calcium Solution: 0.4202 g. $CaCO_3$ dissolved in 20 ml 0.5N hydrochloric acid, boiled to remove CO_2 and made up to 500 ml with CO_2-free water.

   The solution contains 0.3362 mg Ca per ml.

3. Buffer Solution 1: 6.75 g. ammonium chloride, 0.062 g magnesium sulphate ($MgSO_4.7H_2O$), 57 ml concentrated ammonia, (0.880 sp.gr.) 0.093 g E.D.T.A., dissolved in water and made up to 100 ml; 17 ml of this solution diluted to 50 ml.

4. Buffer Solution 2, pH = 10: 33.75 g ammonium chloride and 285 ml concentrated ammonia (sp.gr. 0.88) made up to 500 ml with distilled water.

5./

RESULTS

Table 1. Titration of Synthetic solutions

Solution	Ca present	Ca detd.	Mg present	Mg detd.
1	1.43 mg	1.46 mg	1.20 mg	1.21 mg
2	3.57	3.59	1.20	1.21
		3.58		1.24
		3.60		1.22
Mean		3.59		1.22
St. Devn.		$\pm$ .008		$\pm$ .016
3	7.14	7.16	1.20	1.24
4	3.57	3.60	0.60	0.62

Table 2. Interfering Ions

	Titration A		Titration B	
Ions	Amount	Effect	Amount	Effect
Fe	0.1 mg	pink tinge at end-point		
	0.36 mg	precipitate	0.4 mg	precipitate
Mn	0.16 mg	pink tinge		
			0.36 mg	precipitate
PO_4			2-3 mg	precipitate

5. Solochrome Black Indicator: 0.2 g of solochrome black (B.D.H.) and 50 g of sodium chloride mixed and ground to pass a No. 52 B.S.S. sieve.

6. Murexide Indicator: 0.2 g of murexide (B.D.H.) and 100 g of pure sodium chloride mixed and ground to pass a No. 52 B.S.S. sieve.

In order to test these reactions quantitatively, solutions containing known amounts of calcium and magnesium were titrated with 0.018N E.D.T.A. The calcium was varied from 1 to 7 mg and the magnesium from 0.6 to 1.2 mg, amounts consistent with those which might be found in about 0.8 g dry plant material. In addition to calcium and magnesium, each titrating solution contained 0.031 g ammonium chloride and sufficient distilled water to bring the volume to 50 ml. For the solochrome black titration (A), 3 ml 2.6 per cent ammonium hydroxide and 0.2 g solochrome black were added. For the murexide titration (B), 7 ml N/3 sodium hydroxide and 0.2 g murexide indicator were added.

The results (see table 1.) were satisfactory when calcium and magnesium were present in approximately equivalent amounts but as the relative amounts of magnesium decreased, with a corresponding smaller difference between the titres, there was a tendency to overestimate the magnesium, a point emphasised by Willson (67).

Interfering Ions./

Interfering Ions. (Table 2).

To find the limits of interference of iron, maganese and phosphate, solutions containing varying concentrations of these ions, in addition to calcium and magnesium, were titrated with E.D.T.A.

Each titrating solution contained 3.57 mg Ca and 1.20 mg Mg.

Interference of Iron.

The amounts of iron added to the titrating solution varied from 0.1 to 0.6 mg Fe (added as $FeCl_3.6H_2O$).

In the solochrome black titration (A), it was found that if more than 0.1 mg iron is present, a faint pink tinge remains in the solution at the end-point, and if more than 0.36 mg is present, the precipitate of ferric hydroxide which forms, masks the end-point and a definite pink tinge remains in the solution.

Iron does not affect the murexide titration (B) to the same extent but with larger amounts of iron (0.4 mg) the precipitate of ferric hydroxide tends to obscure the end-point.

The limit of iron for A, 0.1 mg, corresponds to some 125 parts per million dry plant material, and the limit for B, 0.36 mg, corresponds to 450 ppm. Since the iron content of plant material commonly varies from about 100 to 500 ppm. iron must obviously be removed from the solution prior to titration.

Interference of Manganese./

Interference of Manganese.

The amounts of manganese added to the titrating solution varied from 0.16 to 0.6 mg (added as $MnCl_2.4H_2O$).

It was found that manganese interferes in both titrations to a certain extent. If more than 0.16 mg manganese is present in the titrating solution, a pink tinge remains at the end-point in titration A and results tend to be high. In the murexide titration (B), more than 0.3 mg of manganese interferes with the end-point owing to the formation of a precipitate. The manganese content of plant material may vary from less than 20 ppm to more than 500 ppm and these limits of 0.16 and 0.3 mg correspond to 200 and 375 ppm respectively.

Interference of Phosphate.

The phosphate in plant material may vary from about 0.4 to 1.3 percent (as PO_4) the former figure corresponding to 3.2 mg in the titrating solution. Phosphate interferes in both titrations but more seriously in B on account of the precipitation of calcium phosphate, and a false end-point appears on addition of E.D.T.A. On standing or shaking, it disappears but the nearer the true end-point, the longer the false end-point persists so that in presence of even 2 or 3 mg of phosphate (added as sodium dihydrogen phosphate), one tends to overestimate the calcium and an accurate titration becomes virtually impossible. It has been suggested that phosphate interference can be overcome by addition of an excess/

excess of E.D.T.A. followed by back titration with standard calcium solution, but the end-point is still not very satisfactory.

Interference of Ammonium Chloride.

Ammonium chloride is required in the titration A to exert a buffering action with ammonium hydroxide, but is interferes in titration B. Amounts of the salt varying from nil to 0.25 g were added to titrating solutions and the effect on the end-points observed.

When more than 50 mg ammonium chloride are present in 20 ml of the titrating solution, the murexide indicator turns orange instead of pink and there is no definite end-point. The optimum amount for titration A appears to lie between 25 and 50 mg in the titrating solution. Since the solution prepared from the plant extract contains considerably more than this, most of it must be removed by boiling with sodium hydroxide.

Removal of Interfering Ions.

a. Iron and Manganese. It was decided to remove iron and manganese from solution by precipitation and filtration. Solutions were prepared containing calcium, magnesium, iron and manganese in amounts comparable to those present in 8-10g. dry plant material. Iron was precipitated as ferric hydroxide with ammonium hydroxide in presence of a limited amount of ammonium chloride. Ammonium persulphate was then added to precipitate manganese, the solution being kept just/

that red to mahogany red. The precipitates were removed by filtration through Whatman No. 42 filter paper and the solution made up to 250 ml. 20 ml. aliquots were used for titration.

The results are shown in [illegible]

Double precipitation of iron and manganese and combination of the two filtrates resulted in little difference in the titration for calcium and magnesium showing that little or no calcium had been adsorbed into the ferric precipitate.

(c) Phosphate - 1. [illegible]. Various authors (33) have reported the use of anion-exchange resins for removal of phosphate from solutions. It was thought that this method might be suitable for application to plant materials.

The resins were tested (1) Amberlite IR 120(H) and (2) De-acidite FF. Two types of column were used (a) a small glass column consisting of a glass tube with a rubber [illegible] and clip at the bottom (b) a larger glass tube with glass [illegible] and tap. [illegible]

Preparation of Resin Column

[illegible] in [illegible] HCl and then thoroughly washed with further volumes of [illegible] and distilled water.

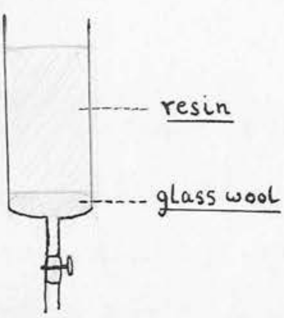
Table 3a. Synthetic solutions (3.57 mg Ca, 1.21 mg Mg)

Removal of Interfering Ions (1)

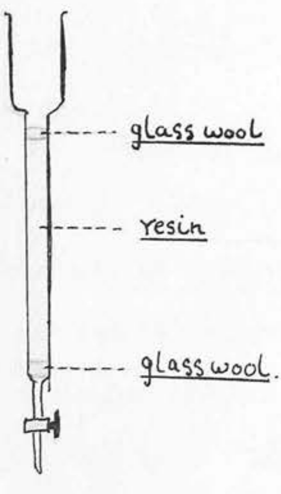
Additions	Ca detd.	Mg detd.
Fe and Mn*	3.56	1.22
	3.57	1.20
	3.58	1.20
	3.57	1.20

* Added ions removed by precipitation.

Resin Columns.



(a)



(b)

just red to methyl red. The precipitates were removed by filtration through Whatman No. 41 filter paper and the solutions made up to 250 ml; 20 ml. aliquote were used for titration.

The results are shown in Table 3a. The tendency is to underestimate the calcium and the magnesium slightly.

Double precipitation of iron and manganese and combination of the two filtrates resulted in little difference in the titration for calcium and magnesium showing that little or no calcium had been adsorbed into the first precipitate.

b. Phosphate - 1. Resin Column Method. Various authors (23) have recorded the use of anion-exchange resins for removal of phosphate from solutions. It was thought that this method might be suitable for application to plant extracts.

Two resins were tried (1) Amberlite IR 4b(OH) and (2) De-acidite FF. Two types of column were used (a) a small trial column consisting of a glass tube with a rubber outlet and clip at the bottom (b) a large glass tube with glass outlet and tap. (see opposite)

Preparation of Resin Column.

(1) Amberlite IR 4b (OH). The resin was soaked overnight in 2N HCl and then thoroughly washed with further volumes of 2N HCl and distilled water.

(2)/

(2) De-acidite FF. The resin was soaked in water for five minutes, treated with 2N HCl until free from effervescence and washed with distilled water.

In both cases, the resin was transferred to the column in a slurry with distilled water, allowed to settle and then washed with 2N HCl followed by distilled water.

Regeneration of column: after use, the column was "back washed" with distilled water by dipping the outlet tube into a beaker of water and applying gentle suction at the top of the tube. It was then washed with 100 ml 2N HCl followed by distilled water.

(a) Trial columns.

50 ml solutions of potassium dihydrogen phosphate containing 80 mg PO_4 were passed through the trial columns at the rate of 15 ml/min. The effluent solutions were free from phosphate when tested with the stannous chloride-molybdate test.

(b) Standard columns.

50 ml solutions containing 80 mg PO_4 (as potassium dihydrogen phosphate) and 1.5 mg iron (as $FeCl_3.6H_2O$) were prepared, treated with ammonium hydroxide and hydrochloric acid until the solution was just red to methyl red, warmed to 60°C, cooled and passed through the column. Removal of phosphate was complete, but some difficulty was experienced with the faint precipitate of ferric phosphate which blocked the top of the column. This was overcome by introducing a filter funnel containing paper maché and glass wool at the top of the column to catch any precipitate which formed.

<u>Estimation</u>/

Table 3b Synthetic solutions (3.57 mg Ca, 1.20 mg Mg)

Removal of Interfering Ions (1)

Series	Additions	Ca detd.	Mg detd.
A	Fe and PO_4*	3.54	1.24
		3.55	1.24
B	Fe, Mn and PO_4*	3.54	1.21
		3.54	1.21

* (added ions removed by precipitation) and column.

Table 4. Synthetic solutions (3.57 mg Ca, 1.21 mg Mg)

Removal of Interfering Ions (2)

Series	Additions	Ca detd.	Mg detd.
A	Nil	3.54 mg	1.22 mg
		3.56	1.20
B	Fe, Mn and PO_4 (removed by precipitation)	3.58 mg	1.20 mg
		3.54	1.23
		3.54	1.22
		3.52	1.23
		3.56	1.21
Mean		3.55	1.22

Estimation of Calcium and Magnesium in synthetic solutions.

50 ml solutions containing calcium, magnesium, iron, manganese and phosphate in amounts comparable to those which might be found in 8 - 10 g dry plant material were prepared, treated as in b (above) and passed through columns. The effluent and 50 ml washings were collected, evaporated to about 150 ml and treated with ammonium chloride, ammonium hydroxide and ammonium persulphate to precipitate manganese. The precipitate was removed by filtration through a Whatman No. 41 filter paper and the filtrate and washings, together with the remaining washings from the column, made up to 250 ml. Aliquots of 20 ml were used for titration with E.D.T.A. The results (Table 3b) showed that this method was satisfactory.

Estimation of Calcium and Magnesium in Plant Material.

Approximately 10 g of dried grass were weighed out, ashed and the mineral matter extracted with hydrochloric acid as described on page 38. The iron, manganese and phosphate were removed as described above and the solution made up to 250 ml.

It was found that the phosphate was not being completely removed from the solution because of the large amount of chloride present after extraction of the plant ash, which was preventing proper ion exchange on the column. It was decided therefore to seek some other method of phosphate removal.

Removal/

2. Removal of Phosphate by Precipitation.

The method finally adopted was that of double precipitation of phosphate as ferric phosphate at pH 3-4 by addition of a slight excess of ferric chloride, any excess iron being removed as hydroxide.

Method of analysis of Plant Material.

Ignite 10g. of plant material at a dull red heat and treat the ash to render the silica insoluble. Take up with hydrochloric acid, filter and add to the filtrate an excess of 10 percent aqueous ferric chloride, warm the solution, and adjust the pH by addition of ammonium hydroxide and acetic acid until the solution is just red to methyl red - used externally. Heat the solution to boiling point, and filter as quickly as possible through a Whatman No. 41 filter paper supported in the funnel by a hard paper cone so that suction can be applied if necessary (filtrate A). Dissolve the precipidate in 2N hydrochloric acid, reprecipitate as before and filter (filtrate B).

Evaporate the first filtrate (A) to 150 ml, make the solution just alkaline to methyl red with 1.5N ammonium hydroxide, and precipitate the manganese as manganese dioxide with either bromine-water or ammonium persulphate as oxidant. Filter off the precipitate, combine the filtrate with filtrate B, make the solution just red to methyl red and adjust the volume to 250 ml.

Use 20 ml. aliquots for titration with 0.018N E.D.T.A.

Titration/

Titration A.

To 20 ml solution, add 30 ml water, 3.5 ml buffer solution (2) and 0.2 g. solochrome black indicator. Titrate with E.D.T.A. until the colour changes from wine red to blue.

Titration B.

Remove most of the ammonium chloride, by boiling with sodium hydroxide,readjust the pH so that the solution is just red to methyl red, add 7 ml 0.3N sodium hydroxide to bring the pH to 12, then 0.2g murexide indicator and titrate with E.D.T.A. until the colour changes from pink to purple.

The end-point is rather difficult to see at first. Connors (10) has suggested a useful standard consisting of 60 ml of a saturated solution of borax and 2 drops of cresol r red (0.4 percent). The E.D.T.A. is added to the titrating solution until the colour matches that of the standard. A north light is best for the titration but a white-lined titrating cabinet with two colour-matching strip lamps (18W.) has proved to be very satisfactory. More recent work (48) suggests that the end-point with murexide can be improved by addition of methylene blue.

Results

All the results given are calculated from the means of duplicate titrations.

Synthetic solutions.

Solutions were prepared containing A: calcium and magnesium in amounts comparable to those found in 10g dry plant material/

Table 5. Comparison of E.D.T.A. and conventional methods for Grass mixture

	E.D.T.A. Method		Conventional Method	
	% Ca	% Mg	% Ca	% Mg
	0.718	0.145	0.738	0.141
	0.712	0.130	0.748	0.145
	0.732	0.150	0.749	0.146
	0.728	0.145	0.717	-
	0.726	0.141		
	0.722	0.139		
	0.741	0.151		
	0.720	0.144		
Mean	0.725	0.143	0.738	0.144
St. Devn.	± .008	± .006	± .013	

Table 6. Recovery of magnesium added to grass mixture (E.D.T.A. method)

	% Ca	% Mg
	0.723	0.201
	0.738	0.209
	0.723	0.209
	0.712	0.203
Mean	0.724	0.206
St. Devn	±.009	±.004

material,

and B: 1.5mg Fe, 2.0mg Mn and 80mg PO_4 in addition to calcium and magnesium as in A. The interfering ions were subsequently removed by precipitation as described.

Solutions A and B were made up to 250 ml and 20 ml aliquots used for titration.

The results are shown in Table 4. (P.36).

<u>For Plant Extracts</u> the results are in satisfactory agreement with those obtained by the conventional oxalate-permanganate method for calcium followed by the magnesium ammonium phosphate precipitation and determination of magnesium as pyrophosphate (46). A series of analyses was carried out on a composite milled sample of grass herbage from several fields, 10 g portions being used for each analysis. The results for a series of 8 analyses by the E.D.T.A. method and 4 analyses by the conventional method are given in table 5. Variations in the figures include the error in sampling, which is usually greater than the analytical error in material of this type.

<u>Recovery of added magnesium.</u>

To each of four 10g samples of the grass mixture, 5.9mg of magnesium (as $MgSO_4.7H_2O$) were added and the calcium and magnesium determined. The results in table 6 show that recovery of the magnesium was good.

<u>Conclusion.</u>

The method is almost as accurate as the conventional methods and quicker for a small number of samples, but the number/

number of samples which can conveniently be dealt with simultaneously is smaller owing to the amount of handling necessary. The method is therefore useful for research purposes, or for analysis of a few samples where results are required quickly, but is not so suitable for routine purposes. In view of this, it was decided to use the conventional methods in the analyses of the samples.

Conventional method for Determination of Calcium and Magnesium.

5 g. dry plant material are ignited at dull red heat for several hours and the ash treated with concentrated hydrochloric acid to render silica insoluble. The residue is taken up with hydrochloric acid and filtered through a Whatman No. 41 filter paper into a 250 ml. beaker. 5 ml concentrated hydrochloric acid are added and the calcium precipitated as oxalate at pH 4-5. The oxalate precipitate, after standing overnight, is filtered, dissolved in 2N sulphuric acid and titrated with permanganate. The iron, manganese and phosphate which might interfere in the precipitation remain in solution at pH 4-5 in presence of acetate ions. A small amount of ferric phosphate may be precipitated with the calcium oxalate but does not interfere in the titration. Magnesium is precipitated as magnesium ammonium phosphate in the filtrate from the calcium precipitation with sodium phosphate and ammonium hydroxide and is determined by conversion to the pyrophosphate by ignition at 900°C/

$900^{o}C$ and weighing. Iron remains in solution in presence of sodium citrate. Manganese may be precipitated with magnesium and can be estimated colorimetrically after ignition but in extracts of plant ash the amount of manganese precipitated is generally negligible, and can be ignored. (Piper: "Soil and Plant Analysis" (46))

b. Determination of Phosphate.

1g of dried plant material is boiled with a mixture of nitric, sulphuric and perchloric acids and the silica removed by filtration. After evaporation of the filtrate to about 100 ml. phosphate is determined by precipitation as ammonium phospho-molybdate with Lorenz molybdate solution (as described in Piper's "Soil and Plant Analysis", p.(46)). The precipitate is filtered into a weighed glass crucible, washed with alcohol and ether, dried in vacuo and weighed.

2. Soils

a. Determination of Calcium and Magnesium.

25g of air-dried soil were treated with 100 ml 0.5N acetic acid and allowed to stand overnight. The acetic acid was removed by filtration and the soil leached with 0.5N acetic acid until 500 ml extract had been collected. The solution was evaporated to 200 ml and calcium precipitated as oxalate by addition of hot saturated ammonium oxalate to the boiling solution, the pH having been adjusted to 4-5 by addition of ammonium chloride and ammonium hydroxide. After standing overnight/

overnight and filtering, the oxalate precipitate was determined by titration with potassium permanganate. Magnesium was precipitated as magnesium ammonium phosphate in the filtrate and determined as the pyrophosphate by ignition and weighing. (Piper.(46))

b. Determination of pH.

The pH of soils was determined using a glass electrode on a mixture containing 1 part of soil to 2.5 parts of water (by volume).

c. Determination of Potassium.

The potassium was determined by the growth of <u>Aspergillus niger</u> in a nutrient solution, complete except for potassium, to which 2.6g soil had been added. The mycelium produced was washed, dried and weighed; the weight is proportional to the amount of available potassium present in the soil. The results were recorded as cg. mycelium/2.5g soil and converted to g.K/100g. soil. The limits were:-

less than		0.004	very low
0.0040	-	0.0083	low
0.0090	-	0.012	medium - low
0.013	-	0:021	medium
0.022		upwards	high.

d. Determination of Phosphorus.

5g soil were extracted with 0.2N hydrochloric acid and filtered. Phosphorus was determined in the filtrate by addition/

addition of ammonium molybdate and stannous chloride and measurement of the colour-complex so formed on an Eel colorimeter.

The results were recorded as: P in g/100g soil

The limits were:-

0.004	- 0.009	very low
0.013	- 0.021	low
0.026	- 0.035	medium - low
0.039	- 0.065	medium
0.070	- 0.109	high
0.113	upwards	very high.

SECTION III

Experimental

A. To find the seasonal variation in the magnesium content of various species of grass and clover and the effect of nitrogenous fertilisers thereon.

Site: House Park Field, Boghall.

A1. Danish Cocksfoot with White Clover.

A2. Ayrshire Ryegrass with White Clover.

Each experiment consisted of four rows of randomised plots, each row containing twelve plots, in pairs, of various strains of grass and clover, six treated with nitrogen and six left untreated.

A3. Italian Ryegrass and Red Clover.

This experiment consisted of four rows of randomised blocks, each row containing eight plots in pairs, of various species of ryegrass and red clover, four treated with heavy dressings of nitrogenous manure and four with light dressings. The species chosen for analysis was Italian Ryegrass.

Sampling

1. Cocksfoot with White Clover.
2. Perennial Ryegrass and White Clover.

The plots were cut monthly in 1953 and 1954 with a motor scythe two strips being cut in each plot, and the centre strip being left uncut. The weight of grass and clover from each plot was found.

Area/

Area each plot (1) 4 x 10 sq. yds. (2) 3 x 14 sq. yds.
area cut 2 x 8 " " 2 x 12 " "

The samples for chemical analysis were taken from the two plots in each row which contained (1) Danish Cocksfoot and White Clover and (2) Ayrshire Ryegrass and White Clover, and were cut at random, with shears, from the uncut portion in the middle of each plot after cutting for yield. The four samples from the nitrogen treated plots were carefully mixed in the laboratory and a sub-sample taken. The grass and clover in the sub-sample were separated. The same procedure was used for the nitrogen-free plots.

The samples were taken at monthly intervals from April onwards during 1953 and two-monthly intervals during 1954.

After cutting and sampling, the +N plots were treated with nitrochalk at the rate of 2 cwts/acre/cut.

Sampling error

To give some idea of the variation in chemical content from plot to plot, the grass and clover in each of the four treated and four untreated plots at one cut in each experiment were analysed separately. This was done in the 1st cut with (2) and the fifth cut with (1).

(3) Italian Ryegrass and Red Clover.

The plots were cut with a motor scythe at intervals of six weeks, two strips being cut in each plot and the centre strip left uncut. The total yield from each plot was found.

The/

The samples for chemical analysis were taken from the two plots in each row containing Italian Ryegrass and red clover, and were collected and treated in the same way as the cocksfoot and clover samples.

After sampling and cutting the plots were treated with nitrochalk as follows:

Light dressing: $1\frac{1}{2}$ cwts./acre (N.L.)

Heavy " : 3 cwts./acre (N.H.)

Sampling error.

At the 2nd cut, the samples for chemical analysis from the N.L. plots were mixed in pairs, a sub-sample taken from each pair, to give an idea of the variation from row to row. The same procedure was carried out with the N.H. plots.

Results

Yields * The yields of the grasses and clovers varied greatly during both seasons. The total yield of Danish Cocksfoot was of the same order during the two seasons. In 1953 it showed its maximum yield in June, but in 1954 the maximum was reached in May with a smaller peak in September. The yield of the Ayrshire ryegrass was similar to the cocksfoot yield in 1953 but dropped to about half its value in 1954. The maximum yield was reached in May in the first year with a smaller peak in August, but in 1954, the maximum yield was reached in April after which the yield decreased steadily.

Treatment with nitro-chalk increased the yield of both grasses throughout the season, the effect being greatest on cocksfoot and altered the period of maximum yield. The cocksfoot/

* **Appendix table 3-6 & figs. 1-8.**

cocksfoot reached its maximum yield under treatment in May in both years but showed in addition smaller rises in July and September in the second year. The treated ryegrass also showed a maximum yield in May in both years with a smaller increase in August in 1953 and in July in 1954.

It was thought that these slight variations in periods of maximum yield might be related to different weather conditions during the two years but examination of monthly rainfalls and number of hours of sunshine failed to produce any abvious relationship. It is possible that the variations were due to a combination of factors.

The monthly yields of white clover varied even more during the season than did those of grasses. The total seasonal yield of white clover from the cocksfoot plots was similar to that from the ryegrass plots, but the seasonal variation was affected by the grass with which it was grown. Both series of white clover increased in yield to a maximum in June, after which the clover grown with cocksfoot decreased steadily in yield, whilte the "ryegrass clover" reached a further peak in August before decreasing.

Treatment with nitrochalk depressed the yield of white clover on both series of plots, the effect being more pronounced on the cocksfoot plots. The "cocksfoot clover" increased slightly in yield in May and then decreased to almost nil in August and September, while the "ryegrass clover" showed a maximum yield in June followed by a much more gradual decrease.

The/

The seasonal variation in yield in the two series of white clover seems to follow the variation in yield of the grass with which it is grown. The difference in the effect of nitrochalk on the yields of the two series of white clover appears to be due to the competition between the grass and the clover. The yield of cocksfoot, a very leafy grass, was increased so much by the nitrochalk that the clover was depressed, until by August it was reduced to nil.

Note.

The yields of the different grasses and clovers were recorded by the Advisory Botany Department. The total yield from each plot was measured and a sample taken for botanical analysis. The yields of the individual grasses and clovers were then calculated. A brief discussion of the results obtained is given above to clarify the results of uptake of minerals discussed later.

Mineral Content.

A1 Danish Cocksfoot and White Clover

A2 Ayrshire Ryegrass and White Clover.

% Ash (Appendix 3 & 4)

The ash contents of the two grasses were of the same order of magnitude. The ash content of the cocksfoot rose steadily until August and then fell slightly while that of the ryegrass rose until June, dropped slightly in July and then continued to rise.

% Calcium

The Danish cocksfoot had a considerably lower calcium content throughout the season than did the Ayrshire Ryegrass (App. Tables 3 & 4) and the seasonal variation was different (figs. 9, 10). In the cocksfoot, the calcium content dropped slowly to a minimum in May and then rose steadily until the end of the season, while in the ryegrass, after a slight decrease in May, it increased sharply to a peak in June, and then dropped slightly in July but remained high for the rest of the season.

The calcium contents of the two series of white clover were much higher than that of either of the grasses, and showed different seasonal variations to the grasses and to one another (figs. 15, 16). The calcium content of the clover grown with cocksfoot rose sharply to a maximum in May, and showed another smaller peak in August, while that of the "ryegrass clover"/

clover" rose steadily to a maximum in August and dropped sharply in September, the only similarities between the two being the rise in May and the fall in September.

In 1954, the calcium content of the grasses was about the same in May and slightly higher in July and September while that of the clover grown with cocksfoot was slightly higher throughout the season and of the "ryegrass clover" was lower in May and July and slightly higher in September.

% Magnesium

The magnesium content of the two grasses (App.tables 3&4) was about the same and was lower than the calcium content. In the cocksfoot, the magnesium content rose slowly until June, dropped slightly in July and then rose again in August; in the ryegrass, the seasonal variation was similar but the June maximum and the July minimum were more pronounced while the August peak was lower, due possibly to competition between the clover and the ryegrass, which showed an increase in yield in August. (figs. 11, 12)

The magnesium contents of the white clover (App. table 5) in the two series of plots were of a similar order and were higher than those of the corresponding grasses, but the seasonal variation varied with the grass with which it was grown (figs. 17, 18) The magnesium content of the "cocksfoot clover" rose in May and then remained more or less constant until September when it fell slightly, while that of the ryegrass showed two maxima - in June and in August - with a slight/

slight drop in July.

In 1954, the magnesium contents of the grasses were similar to the 1953 values, while those of the clovers were lower.

% Phosphorus

The phosphorus contents of the two grasses (App. tables 3,4) were of the same order and were higher than either the calcium or the magnesium contents. The seasonal variation of phosphorus in the cocksfoot (fig. 13) was similar to that of the magnesium with an increase in May and June and a further increase in August. The phosphorus content of the ryegrass showed a similar variation (fig. 14) with a more pronounced maximum in June but a smaller increase in August.

The phosphorus content of the white clover grown with cocksfoot was slightly lower initially than that of the clover grown with ryegrass, probably because of more successful competition with the ryegrass than with the cocksfoot, but by the end of the season, the two were about the same (App. table 5). The seasonal variations in phosphorus contents were different; (figs. 19,20) that of the "cocksfoot clover", after an initial drop in May, rose to a maximum in July and then dropped sharply in August, while that of the "ryegrass clover" fell in May and June, remained constant in July, dropped again in August but rose slightly in September.

In 1954, the phosphorus content of the grasses was lower in/

in May and September than in 1953, but higher in August.

In most cases, the difference in the content of each element from month to month was greater than the standard deviation of that element between the four plots. The standard deviations of the grasses are given in table 7 (Appendix) and of the white clover in table 8 (Appendix).

Treatment with "Nitrochalk"

% Ash (Appendix: Tables 3,4).

The ash content of the grasses was slightly increased by the first and second applications of "nitrochalk" but from the third cut onwards was slightly depressed. In both grasses, the ash content of the treated grass rose from April to June, fell slightly in July and rose again in August.

% Calcium

Treatment with "nitrochalk" increased the calcium content of both grasses throughout the season (App. tables 3,4) except in the July cocksfoot where the values for treated and control grass were the same. The cocksfoot was still lower in calcium content under treatment than was the ryegrass. The seasonal variation in calcium content (figs. 9,10) was not greatly altered except that the treated cocksfoot showed a slight decrease in June instead of an increase.

The calcium content of the treated clover was of the same order on the two plots and the seasonal variation was similar (App. table 5, & figs. 15,16) Both values increased to a maximum in August, the ryegrass clover rising steadily, while the/

the cocksfoot clover rose until May, remained constant until July and then rose sharply. Because of the difference in calcium content between the clover from the two series of plots, the treatment appeared to have depressed the calcium content of the clover on the cocksfoot plots and increased it on the ryegrass plots.

% Magnesium

Treatment with "nitrochalk" increased slightly the magnesium content of the cocksfoot from May onwards and of the ryegrass throughout the season, but did not appreciably alter the seasonal variation of either except in September when the values rose instead of dropping (figs. 11, 12).

Treatment with "nitrochalk" appeared to depress the magnesium content of the "cocksfoot clover" until July, after which it rose above that of the control clover and continued to increase until September, while on the ryegrass plots, treatment appeared to increase the magnesium content of the clover initially, but to depress it from July onwards (figs. 17, 18).

This differential effect of "nitrochalk" on the calcium and magnesium contents of the two series of white clover seems to be due to the competition between the grass and the clover for the available minerals in the soil, but the reason for it is not clear. It does not occur with the phosphorus content.

% Phosphorus

Treatment with "nitrochalk" increased the phosphorus content

of/

of both grasses initially but depressed it from June onwards, (App. tables 3,4) and altered the shape of the two curves showing seasonal variation. The phosphorus content of the treated cocksfoot dropped to a minimum in July, and then rose slightly in August and September, while that of the ryegrass showed a maximum in June, dropped in July and then rose sharply in September (figs. 13,14).

The depressing effect of "nitrochalk" agrees with the results of Fagan et al (17) who report that applications of sodium nitrate depressed the phosphorus content of herbage, and Williams & Evans (66) who state that "nitrochalk" depressed the phosphorus content of Italian ryegrass.

Treatment with "nitrochalk" increased the phosphorus content of both series of white clover initially, but depressed it from July onwards (figs. 19, 20). The phosphorus content of both series of treated clover dropped steadily during the season, that of the ryegrass clover rising again in September. The figures of the cocksfoot clover from July onwards were not available.

In 1954, the effect of "nitrochalk" on the mineral content of the cocksfoot was similar to that in 1953, but in the ryegrass, the effect on the magnesium and phosphorus contents appeared to vary. The calcium and magnesium contents of the white clover grown with ryegrass were depressed initially, but by the end of the season there was unsufficient clover left to analyse. There was no clover on the treated cocksfoot plots in 1954.

A3/

A3 Italian Ryegrass and Red Clover.

% Ash

The ash content of Italian ryegrass treated with light and heavy dressings of "nitrochalk" was similar to that of the perennial ryegrass at the beginning of the season, but decreased from then until the final cut when it rose slightly. The heavy dressings tended to depress the ash content (App. table

% Calcium (App. tables 6,9. & figs. 21,22).

The calcium content of the Italian ryegrass decreased steadily until August and then rose slightly in the final cut, the variation being the opposite of that of the yield. The heavy dressing of "nitrochalk" appeared to increase the calcium content in the second and fourth cuts, but had no effect in the others.

9 The calcium content of the red clover was 3-4 times that of the grass, and increased steadily from May onwards, while the yield fell. In September, the calcium content continued to rise, but less sharply, while the yield also rose. Treatment with heavy dressings of "nitrochalk" raised the calcium content even more.

% Magnesium (Figs. 23, 24).

The magnesium content of the ryegrass was less than the calcium content but showed an increase in the second and fourth cuts. Treatment with heavy dressings of "nitrochalk" increased/

increased the magnesium content compared with light dressings except in the third cut.

The magnesium content of the red clover was higher than that of the grass, and increased steadily throughout the season. Treatment with heavy dressings of "nitrochalk" increased the magnesium content in the second and third cuts.

% Phosphorus (figs. 25, 26).

The phosphorus content of the ryegrass was higher than that of the magnesium but showed the same seasonal variation. It appeared to be slightly lower than that of the perennial ryegrass throughout the season. Treatment with heavy dressings of "nitrochalk" appeared to have little effect on the phosphorus content.

The red clover had a slightly higher phosphorus content. than the Italian ryegrass initially, but it dropped steadily throughout the season. Treatmant with heavy dressings appeared to increase the phosphorus content slightly.

Discussion

The mineral content of the grasses and clovers was found to vary considerably from species to species and from month to month throughout the season under a system of monthly or six-weekly cuts.

Under a system of monthly cuts, Danish cocksfoot had a lower calcium content than Ayrshire ryegrass, but higher magnesium and phosphorus contents. The content of all three minerals/

minerals was found to be higher in both the cocksfoot and the ryegrass towards the end of the season when the yields dropped than at the beginning.

The magnesium and phosphorus contents of both grasses showed similar seasonal variations, the changes being more marked in the ryegrass than in the cocksfoot. The calcium content of the ryegrass showed a similar curve but the cocksfoot differed. This seasonal variation in mineral content appears to depend partly on the variation in yield, the mineral content tending to drop slightly during a period of sudden growth, but it has been suggested that the changes in mineral content depend also on the ratio of leaf to stem. Fagan and Milton (17) found that the calcium content of the leaf in grasses was always higher than that of the stem and while it fell in the leaf with age, it increased in the stem, so that the calcium content of the grass would depend on the age and the proportion of leaf to stem. Stapledon (56) found that under a fairly lenient system of cuts, the stem outyielded the leaf during the period of maximum growth in May and June, after which the leaf outyielded the stem, so that the calcium content of the grass will tend to increase as the proportion of leaf to stem increases. This could account for the increase in calcium content of the cocksfoot in July, August and September, and the high calcium content of the ryegrass during these months.

The phosphorus contents of the leaf and the stem do not appear to differ greatly (Fagan et al, 17.), and Evans (16) states/

states that under a system of monthly cuts, the phosphorus content of the herbage increases steadily during the season. The results obtained from Boghall do not however confirm this.

The white clover was found to be richer in calcium and magnesium than either of the grasses, but the phosphorus content varied. Williams and Evans (66) report similar results for the calcium contents of white clover and Italian ryegrass.

Effect of Treatment

The application of "nitrochalk" increased the calcium and magnesium contents of both Danish cocksfoot and Ayrshire ryegrass, but did not appreciably alter the seasonal variation nor prevent the drops in mineral content which occurred at certain periods. It increased the phosphorus content of both grasses initially but depressed it from July onwards. This latter effect is in agreement with results reported in the literature.

The effect of "nitrochalk" on the calcium and magnesium contents of white clover seemed to depend more on the grass with which it was grown. With cocksfoot, the calcium and magnesium contents appeared to be depressed, whereas with ryegrass, they were increased. This difference seems to be due to the effect of the fertiliser on the yield and on the leafiness of the grass and the consequent effect on the competition between the grass and the clover for the available/

available minerals. The phosphorus content of white clover reacted to the fertiliser in the same way as did the phosphorus content of the grass.

Italian ryegrass cut at six-weekly intervals and treated with "nitrochalk" had a higher calcium content than either cocksfoot or perennial ryegrass, but lower calcium and phosphorus contents. The red clover had a similar mineral content to the white clover.

Magnesium - Phosphorus Ratio

The similarity in seasonal variation between the m magnesium and phosphorus contents of the cocksfoot and the perennial ryegrass seems to confirm the reports of certain workers who suggest a relationship between the two elements. (Review of literature p. 8) The ratio of phosphorus to magnesium remains fairly constant at 3:1 (approximately). The relationship does not appear to extend to the clover however and is upset by treatment with "nitrochalk".

From these results, it can be seen that the mineral content of a mixed sward will depend on several factors - the botanical composition of the sward, the frequency of cutting or grazing and the time of year. Swards with a low clover content will tend to be lower in calcium and magnesium than swards rich in clover. The presence of clover in pastures should therefore be encouraged. Application of large amounts of "nitrochalk" as is often the practice will improve the calcium and magnesium contents of the grass but will/

will tend, particularly in a cocksfoot mixture, to wipe out the clover, and continuous applications may lead to a complete absence of clover in the following year with a consequent lower mineral content in the sward.

Results

Uptake of Minerals (A1 and A2)

The uptake of minerals by grasses and clovers depends on two factors - the mineral content of the species concerned and its yield.

Grass (App. table 10 and figs. 27-32).

The total seasonal uptake of minerals varied from species to species. The total seasonal uptake of magnesium and of phosphorus was higher in the cocksfoot than in the perennial ryegrass, but total uptake of calcium was lower. In both grasses, the total amount of magnesium removed from the soil was less than that of phosphorus or calcium. The curves showing the seasonal variation in uptake of each of the three elements were similar to the corresponding grass yield curves in shape. The cocksfoot had a high uptake of calcium from May to August, the maximum being in July, while the uptakes of magnesium and phosphorus reached their maxima in June. The ryegrass had a maximum uptake of all three elements in May with another smaller peak in August.

Clover (App. table 11, & figs 33-38).

The uptake of magnesium and phosphorus was lower in white clover/

clover than in grass, but the uptake of calcium depended on the grass with which the clover was grown. The white clover grown with cocksfoot had a higher uptake of all three elements than did the clover grown with ryegrass. In both series of white clover, the uptake of calcium was greater than that of phosphorus which in turn was greater than that of magnesium. The curves showing seasonal variation in uptake of minerals were similar in shape to the yield curves for clover. The "cocksfoot clover" showed a maximum uptake of all three minerals in June, while the ryegrass showed in addition a second smaller peak in August.

Total (App. table 12 & figs. 39-44)

The total uptake of the three minerals by the grass and clover was slightly greater on the cocksfoot and clover plots than on the ryegrass and clover plots, the difference being most pronounced in the phosphorus. The total amount of calcium removed was greater than that of phosphorus which in turn was greater than that of magnesium. The seasonal variation in uptake was different on the two plots and followed the corresponding grass yield curve in shape. On the cocksfoot plots, the uptake by grass and clover was high in May, June and July, the maximum being in June, the high spring values corresponding to the period of sudden growth of young grass and clover. On the ryegrass plots, the uptake showed two peaks - in May and in August - the first peak being due to the high yield of young grass, while the second increase was due to the increase in yield of both ryegrass and clover.

Treatment/

Treatment with "nitrochalk"

Grass (App. tables 10 & figs. 27-32).

Treatment with "nitrochalk" increased the uptake of each of the minerals estimated, throughout the season, the initial effect being most pronounced in the cocksfoot. The total seasonal uptake of calcium and magnesium was doubled in both species, and the total seasonal uptake of phosphorus was almost doubled. The seasonal variation in uptake was slightly altered in the cocksfoot, The values were still high in May, June and July, but the maximum was reached in May instead of in June. In the ryegrass, the seasonal variation was similar to that of the control plots.

Clover (App. tables 11 & figs. 33-38)

Treatment with "nitrochalk" depressed the uptake of each of the minerals by the clover throughout the season, the effect being greatest in the "cocksfoot clover". The total seasonal uptake by the clover was depressed in the following ratios:-

Uptake of	Cocksfoot plots	Ryegrass plots
Calcium	8 : 1	2 : 1
Magnesium	6 : 1	2 : 1
Phosphorus	6 : 1	3 : 2

The seasonal variation in uptake was altered slightly by treatment. The maximum uptake of each of the elements was reached in May instead of June in the "cocksfoot clover" and depressed to nil in August and September, while in the "ryegrass clover" the maximum uptakes were reached in June instead/

instead of May, and only the calcium and magnesium showed further peaks in August. It can be seen from these curves and the yield figures that the sudden reduction in mineral uptake on treatment is due to the depressing effect on the yield of the clover.

Total (App. tables 12 & figs. 39-44).

The total uptake of the three elements by the grass and the clover was increased fairly consistently throughout the season by treatment with "nitrochalk". The total seasonal uptake was considerably increased except in the case of the calcium uptake on the cocksfoot and clover plots, which was only slightly higher on the treated plots than on the control. The seasonal variation of total uptake by the grass and clover was altered on the cocksfoot plots by treatment. The uptake was still high in May, June and July, but the maximum was reached in May instead of in June. In the case of the calcium, the uptake decreased so rapidly under treatment that in July, it dropped below that of the control grass and clover, the effect being due to the sudden drop in uptake by the clover in that month. On the ryegrass plots, the seasonal variation in uptake of the grass and clover remained almost the same.

Italian Ryegrass and Red Clover A3

Grass (App. tables 13,14,& figs. 45-50).

The uptake of calcium, magnesium and phosphorus by Italian ryegrass receiving light dressings of "nitrochalk" was/

was considerably higher than that of cocksfoot and perennial ryegrass either treated or untreated. The order of removal of the elements was the same as that in the perennial ryegrass. The seasonal variation in uptake was similar for magnesium and phosphorus - a slight increase in the second cut followed by a steady decrease to the end of the season. The uptake of calcium decreased steadily from the first cut onwards.

Treatment with heavy dressings of "nitrochalk" increased the uptake of all three elements, without altering the seasonal variation except in the calcium, where there was a slight increase in the second cut.

Clover

The uptake of the three elements by the red clover receiving light dressings of "nitrochalk" was higher than that of the white clover whether grown with cocksfoot or ryegrass and treated or untreated, but was lower than that of the Italian ryegrass. The order of removal of the elements was the same as in the Italian ryegrass. The uptakes decreased steadily as the season progressed.

Treatment with heavy dressings of "nitrochalk" depressed the uptake of all three elements but did not alter the seasonal variation.

Total (figs. 51-53).

The total uptakes of calcium, magnesium and phosphorus by Italian ryegrass and red clover was higher than that by either/

either cocksfoot and white clover or perennial ryegrass and white clover, but were in the same order: calcium > phosphorus > magnesium. The values decreased steadily during the season.

Treatment with heavy dressings of "nitrochalk" increased the uptake of all three elements, but did not greatly alter the seasonal variation, except in the case of the phosphorus, where the uptake increased slightly in the second cut.

Discussion

The uptake of minerals by plants varied considerably from species to species throughout the season. White clover tended to have a lower uptake than grasses because the yields were considerably lower. The uptake of minerals from a mixed sward will therefore depend to a large extent on the botanical composition of the sward. The total amount of calcium removed was greater than that of phosphorus which in turn was greater than that of magnesium.

Treatment of "nitrochalk" altered the uptake of minerals by affecting the mineral content of the species in the sward and the yield of each species. The effect of "nitrochalk" was to increase the total uptake of all three elements by grass and clover, although the effect on the uptake of calcium by cocksfoot and white clover was less than might be expected.

The increase in uptake of magnesium and phosphorus on treatment/

treatment is important when considering the replacement of these elements in the soil. Treatment with "nitrochalk" will increase the available calcium in the soil, but it large amounts of "nitrochalk" are to be applied, the need to replenish the available phosphorus and magnesium becomes urgent particularly in soils low in these elements. This side-effect of a fertiliser such as "nitrochalk" is too often ignored. The need for application of balanced fertilisers has already been stated by Thomas et al (59) and cannot be too strongly emphasised. Continuous application of fertilisers such as "nitrochalk" which increase the yield of grasses and the uptake of minerals can only result in soils which are deficient in available nutrients, with a consequent decline in the quality of the crops grown thereon, unless some study is made of the nutrients concerned and provision of these nutrients made in the form of the appropriate fertilisers.

B. To investigate the seasonal variation in magnesium content of ryegrass and the effect of magnesium fertilisers thereon, and to observe whether the incidence of 'Blind Seed Disease' affects the magnesium content.

'Blind Seed Disease' is a fungal disease affecting ryegrass. It is thought to be caused by a fungus known as P. mucosa which infects the seed and prevents it developing. (69)

It has been reported in the literature that animals eating infected ryegrass died with symptoms similar to those of "grass tetany". It was decided therefore to lay out a pilot experiment using perennial ryegrass with and without Blind Seed Disease to find whether there was any difference in the seasonal variation of magnesium content between the two plots. A third, control plot was also laid down with perennial ryegrass (S.23).

Site: Bush Estate.

Plots: The plots consisted of three strips, each 3 x 15 sq. yds., with a strip of Russian Comfrey between, and were sown with seed at the rate of 30 lb./acre, as follows:

Strip A: healthy seed - free from B.S.D. perennial ryegrass.

B: control seed perennial ryegrass, S.23.

C: severe blind seed infection perennial ryegrass: Danish Victoria.

Treatment:/

Treatment: All plots: 2·5 cwt./acre P_2O_5
0·4 cwt./acre K_2O
3 cwt./acre "nitrochalk".

Half of each strip was treated with magnesium sulphate i.e. 3 x $7\frac{1}{2}$ sq. yds. received 7 cwt./acre $MgSo_4 \cdot 7H_2O$.

Sampling

The plots were sampled at monthly intervals from July onwards in 1954, the grass being scythed over before the final sampling in November, and from April until August in 1955, after which the plots were again cut over.

Results

Mineral Content: The variation in mineral content between the three plots was considerable in some cuts, but did not seem to be consistent or explicable on the basis of the blind seed infection. It seemed to be due to the fact that the soil had not been ploughed for several years and varied considerably in mineral content. The seasonal variation was similar on the three plots. The average contents of calcium, magnesium and phosphorus in the three plots were calculated at each cut and used as an indication of the seasonal variation. (Appendix , Tables 15,16).

% Calcium

The calcium content of the perennial ryegrass was similar to that of the Ayrshire Ryegrass at Boghall in July. It fell in August, showed a slight rise in September and then continued to fall. In 1955, the value was fairly high at the beginning of the season and fell steadily until the last cut in August.

% Magnesium/

% Magnesium

The magnesium content was similar to that of the Boghall Ayrshire Ryegrass in July, 1954. It rose slightly in August, fell again in September and then remained more or less constant. In 1955, the magnesium content fell sharply in April and then remained more or less constant.

% Phosphorus

The phosphorus content was considerably lower than that of the Boghall Ayrshire Ryegrass, but rose steadily from July to November. In 1955, the phosphorus content was moderate initially but fell to a very low value by the end of the season.

Treatment with Magnesium Sulphate

% Calcium

Treatment with magnesium sulphate appeared to have little consistent effect on the calcium content in the first year. In the second cut, the treated plots were higher in calcium than the untreated and in the third and fourth cuts, they were lower. In 1955, the calcium content was depressed by treatment in the first three cuts.

% Magnesium

Treatment with magnesium sulphate increased the magnesium content of the ryegrass throughout the season in both years. In 1954, the effect lasted until October. In 1955, the initial drop in magnesium content in May still occurred but the values were higher than on the untreated plots.

% Phosphorus/

% Phosphorus

Treatment appeared to have little effect on the phosphorus content of the grass in either year.

Conclusions

It would appear from these results, that the incidence of blind seed disease in ryegrass has little effect on the seasonal variation in the mineral content of the grass, in particular on the magnesium content, and is therefore unlikely to be connected with grass tetany as has been suggested.

The difference in seasonal variation of mineral content between the perennial ryegrass allowed to mature and the Ayrshire Ryegrass at Boghall cut monthly is apparent from these results. In the first year, the calcium content fell from July to November, while the magnesium and phosphorus contents rose slightly. In the second year, the contents of all three minerals dropped during the season.

Treatment with magnesium sulphate was effective in raising the magnesium content of the herbage in both seasons, but did not prevent the drop in May. It had no serious effect on the calcium and phosphorus contents, probably because of the initial dressings of superphosphate and nitrochalk. Magnesium sulphate can be strongly recommended as a spring dressing for herbage.

HERBAGE EXPERIMENTS

(a) Downfield

Plan

21 B	D	C	A	25 E	
20 C	A	D	E	16 B	
11 E	C	B	D	15 A	30 yrds.
10 A	B	E	C	6 D	
1 D	2 E	3 A	4 B	5 C	

25 yrds

Area: - Each plot : 6 x 5 sq. yds.
Total area : 30 x 25 sq. yds.

(b) Forteviot : East Bank Field

Plan

1 E	2 C	3 D	4 A	5 B	
10 C	B	E	D	6 A	
11 A	D	B	C	15 E	30 yrds.
20 B	A	C	E	16 D	
21 D	E	A	B	25 C	

25 yrds

To find the seasonal variation in the magnesium content of herbage and the effect of magnesium and potassium fertilisers thereon.

Sites: Downfield Farm, Fife.

Bankhead Farm, Forteviot, Perthshire. (East Bank and New Mill fields.)

Plan of Experiments: See opposite.

Treatments:

All plots received 2 cwt./acre ammonium sulphate.

2 cwt./acre superphosphate.

Individual Plots:

A: control: no treatment.

B: K_1Mg_1: 1 cwt./acre K_2SO_4: $MgSO_4$

C: K_2Mg_2: 2 " " " "

D: K_2Mg_0: K_2SO_4 equiv. to the K in 2 cwt./acre K_2SO_4: $MgSO_4$.

E: K_0Mg_2: $MgSO_4$: $7H_2O$ equiv. to the Mg in 2 cwt./acre K_2SO_4: $MgSO_4$.

Composition of Fertilisers:

(a) Double Salt: K_2SO_4, $MgSO_4$.

28% $MgSO_4$ ≡ 5.43% Mg and 3.5% NaCl.

48.1% K_2SO_4 ≡ 21.6% K, 7.6% Insolubles.

3.4% $CaSO_4$ ≡ 1.03% Ca, 7.1% H_2O

∴ 2 cwt./acre double salt ≡ 0.109 cwt./acre Mg.

(Treatment B) 0.432 " " K.

0.021 " " Ca.

4 cwt./

4 cwt./acre [illegible]

(Treatment 3) [illegible]

(b) [illegible]

[illegible] cwt./ac [illegible]

[illegible]

The soils [illegible] during the season [illegible] and the available [illegible] The latter [illegible] during the season.

[illegible]

Table 7

Results: Soils

Downfield	before treatment	Average rest of season
pH	6.7 - 7.3	7.4 - 7.6
% Ca	0.25 - 0.40	0.35 - 0.51
% Mg	0.027 - 0.039	0.032 - 0.037
% P	0.052 - 0.078 (M-H)	0.019 - 0.030 (M-H)
% K	0.021 - 0.065 (L-M)	0.009 - 0.041 (M.L.-H)
East Bank		
pH	6.8 - 7.7	6.5 - 7.3
% Ca	0.18 - 0.30	0.20 - 0.26
% Mg	0.008 - 0.009	0.009 - 0.011
% P	0.024 - 0.032 (H)	0.010 - 0.024 (M.L.-H)
% K	0.035 - 0.061 (M.L.-M)	0.039 - 0.105 (H)

4 cwt./acre double salt ≡ 0.218 cwt./acre Mg.

(Treatment C) 0.864 " " K.

0.042 " " Ca.

(b) K_2SO_4

0.963 cwt./acre K_2SO_4 ≡ 0.432 cwt./acre K.

(Treatment D)

(c) $MgSO_4:7H_2O$

1.1 cwt./acre $MgSO_4:7H_2O$ ≡ 0.109 cwt./acre Mg.

(Treatment E)

In addition, New Mill field received 4 cwt./acre nitrochalk 1/5/53, 3/6/53 and 31/6/53. i.e. a fortnight before 1st, 2nd and 3rd cuts.

Crops:

1st year grass for hay: Downfield C_1.

East Bank, Forteviot C_2.

2nd year grass for dried grass: New Mill field, Forteviot C_3.

Results C_1 and C_2.

Downfield and East Bank, Forteviot.

Soils:

Downfield:

The soils were neutral and fairly high in available calcium. Both pH and available calcium rose slightly during the season. The available magnesium was medium and the available potassium and phosphate medium to high. The latter two dropped to medium during the season.

East/

Table 8.

Downfield samples

% Ca in D.M. - original samples: 0.700 - 0.770

Treatment	Cut 1st	2nd	3rd	4th	5th
A	0.628	0.537	0.425	0.635	0.553
B	0.651	0.508	0.425	0.548	0.545
C C	0.620	0.522	0.418	0.547	0.560
D	0.639	0.498	0.425	0.697	0.556
E	0.678	0.546	0.481	0.593	0.598
St. error	4.9	0.94	2.99	-	-
Sig. at 5%	±.079	±0.012	±0.032	-	-

% Mg in D.M. - original samples: 0.160 - 0.205

Treatment	1st	2nd	3rd	4th	5th
A	0.187	0.168	0.141	0.192	0.161
B	0.201	0.167	0.137	0.176	0.153
C	0.208	0.164	0.154	0.168	0.154
D	0.181	0.164	0.135	0.163	0.165
E	0.196	0.172	0.147	0.190	0.162
St. error	4.8	1.2	2.9	-	-
Sig. at 5%	±0.023	±0.005	±0.010	-	-

% P in D.M. - original samples: 0.469 - 0.518

Treatment	1st	2nd	3rd	4th	5th
A	0.590	0.37	0.25	0.44	0.36
B	0.588	0.36	0.24	0.42	0.35
C	0.578	0.37	0.25	0.41	0.34
D	0.578	0.35	0.25	0.42	0.37
E	0.588	0.35	0.24	0.43	0.37
St. error	-	1.7	1.2	-	-
Sig. at 5%	-	±0.015	±0.007		

Table 9.

East Bank samples

% Ca in D.M. original sample

Treatment	Cut 1	2	3	4	5
A	0.643	0.483	0.713	0.665	
B	0.608	0.456	0.609	0.741	
C	0.574	0.409	0.685	0.601	
D	0.586	0.458	0.539	0.679	
E	0.625	0.484	0.675	0.648	
St. error	1.61		-	-	
Sig.at 5%	±0.24		-	-	

% Mg in D.M.

A	0.167	0.140	0.184	0.109	
B	0.170	0.138	0.180	0.167	
C	0;173	0.136	0.192	0.148	
D	0.156	0.133	0.166	0.157	
E	0.176	0.146	0.186	0.161	
St. error	1.81	1.99	-	-	
Sig.at 5%	±0.009	±0.007	-	-	

East Bank:

The soils were again neutral and fairly high in available calcium, and the values did not change appreciably during the season. The available magnesium was low initially but rose slightly during the season. The available potassium and photphate were medium to high.

Herbage (opposite and app. tables 17-20).

Downfield: Each result for the 1st three cuts is the average result for separate analyses of subsamples from each of the five plots receiving that particular treatment. Each result for the 4th and 5th cuts is the result of one analysis of a composite subsample from five plots.

East Bank: The results for the 1st two cuts are average results of separate analyses, those for the remainder are results of single analyses of composite subsamples.

% Calcium

The calcium content of the herbage lay within the same range at the two centres, as did the available calcium in the soil, and showed a similar seasonal variation. The original samples and those taken at the first cut in May were high in calcium, after which the values decreased steadily until the grass was cut for hay. The aftermath of young grass showed a sudden increase in calcium content to a value similar to the May value after which it decreased slightly in September.

% Magnesium

The magnesium contents of the young grass, hay and aftermath/

aftermath at East Bank were considerably lower than at Downfield, which was to be expected since the available magnesium in the soil was lower, but the seasonal variation was similar at the two centres. The values dropped steadily until the grass was cut for hay. The magnesium content of the young grass remaining was higher than that of the hay, but dropped slightly towards the end of the season.

% Phosphorus

The phosphorus values for East Bank were not available. In general, the phosphorus content at Downfield followed the same seasonal trend as the calcium and magnesium contents in decreasing steadily until July, and rising again in the young growth after cutting for hay followed by a slight drop at the end of the season.

Effect of Treatments:

1. Magnesium sulphate (E).

% Calcium

Treatment of the herbage with magnesium sulphate appeared to have little effect on the calcium content of the herbage at East Bank. In the fourth and fifth cuts, the treated herbage appeared to have a higher calcium content than that of the control plots but it is probable that any effect of the fertilisers had worn off by then. At Downfield, treatment with magnesium sulphate appeared to have little effect until the fifth cut, where, as at East Bank, the samples were composite subsamples and so significant differences could not be calculated.

% Magnesium/

% Magnesium

At East Bank, treatment with magnesium salts raised the magnesium content of the herbage significantly in the first cut (Table 9 and Appendix Table 17.). In the second cut, herbage from the magnesium treated plots was still higher in magnesium content than the control herbage but the difference was no longer significant. By the third cut, the effect of treatment had worn off and the young growth after the hay showed little difference in magnesium content between the two plots. At Downfield, the effect of magnesium treatment was not significant in may of the cuts but the treated herbage did tend to be higher than that of the control herbage up to the hay stage, after which there was no difference between the plots.

Treatment with magnesium fertilisers was more effective at East Bank, as was expected, since the soil was particularly low in magnesium initially.

% Phosphorus

Treatment with magnesium sulphate appeared, if anything to lower the phosphorus content of the herbage.

2. Potassium sulphate (D).

% Calcium

At East Bank, treatment with potassium sulphate depressed the calcium content of the herbage compared with that of the control in the first cut, the effect being significant at the 1% level. By the second cut, the effect had worn off.

At/

At Downfield, treatment with potassium sulphate appeared to have little effect on the calcium content of the herbage. This may have been due to the fact that during the season the available potassium in the soil dropped slightly at this centre.

% Magnesium

Treatment lowered significantly the magnesium content of the herbage at East Bank during the first two cuts. The effect was still noticeable in the young growth after the hay although significant differences could not be calculated, but by the following month, the effect was negligible.

At Downfield, a slight depression of magnesium content was noticed on treatment but the differences were not significant.

This depressing effect of potassium salts on the uptake of magnesium by plants is in agreement with results reported by other workers. (P.10).

% Phosphorus

Treatment with potassium salts appeared to depress the phosphorus content of the herbage at Downfield in the first two cuts, but by the third cut the effect had worn off.

3. Potassium - magnesium sulphate (B and C).

% Calcium

At East Bank, the calcium content of the herbage was depressed significantly in the first cut by treatment with the double salt in both single and double doses, and in the second cut by the double dose. In the third, fourth and fifth/

fifth cuts, the herbage receiving the double dose was still lower in calcium content than the control herbage showing that general trend was still the same, although the significant differences could not be calculated as the samples were only composite sub-samples. In the first cut, herbage receiving double doses of the salt was also lower in calcium than that receiving magnesium sulphate.

At Downfield, herbage receiving the double dose of the salt was lower in calcium than the control herbage in the second cut only, but was lower than herbage treated with magnesium sulphate throughout the season except for the first cut, the differences being significant in cuts 2 and 3. There were no significant differences in the first cut and it is possible that the fertilisers had not been completely absorbed by the soil since the weather was fairly dry during the month and some of the fertiliser was observed to be still lying on the surface.

% Magnesium

Treatment with the double salt raised the magnesium content of the herbage at both centres in the first cut, although the differences were not significant. At both centres, the herbage receiving a double dose of the salt was significantly higher in magnesium than herbage treated with potassium sulphate, and at East Bank, herbage receiving a single dose of the salt was also higher in magnesium. In the second cut, the magnesium content of both the double and the single-dosed herbage suddenly dropped to a value about/

about the same as that of the control herbage at both centres and significantly lower than that of the magnesium treated herbage. In the third cut, the herbage receiving treatment B (single dose) remained about the same as the control, while the C treatment herbage rose to a value above that of herbage from all the other plots and at Downfield significantly higher than all but the magnesium-treated herbage. Thereafter the values remained high at Downfield but dropped away at East Bank.

<u>% Phosphorus</u>

Treatment with single and double doses of the double salt depressed the phosphorus content of the herbage in the first cut, but thereafter the effect appeared to wear off.

<u>Discussion:</u>

The mineral content of the herbage seemed to depend directly on the available nutrients in the soil. The calcium content at the two centres was similar, as was the available calcium in the soil, but the magnesium content was lower at East Bank where the available soil magnesium was lower.

The seasonal variation in mineral content was similar at the two centres. Both the calcium and the magnesium contents dropped steadily as the herbage matured, until the hay was cut, after which the calcium and magnesium contents of the young growth rose again. The phosphorus content of the herbage at Downfield showed a similar variation/

variation. The difference in mineral content of herbage from these experiments and grass cut monthly at Boghall is striking. The herbage at Downfield, for instance, was initially richer in all three elements than the grass at Boghall. As the herbage matured, the magnesium and phosphorus contents dropped until they were below that of the grass, which showed an entirely different seasonal variation in mineral content. This agrees with the results of Evans (16) and of Fagan (17), and shows the difference between grass which is kept at the young leafy stage by grazing and grass which is grown for hay. The evidence suggests that in feeding hay to cattle, it is advisable to provide some other source of minerals, such as mineral licks.

Treatment of herbage with fertilisers showed varying results. Magnesium sulphate was found to raise the magnesium content of the herbage particularly where the soil was low in available magnesium, but tended if anything to depress the phosphorus content, although the evidence in the latter case was insufficient to draw definite conclusions. The effect on magnesium content was in agreement with results obtained by other workers (P.15), so that the use of this salt to raise the available magnesium in neutral soils can be recommended.

Potassium sulphate was found to depress the calcium content of herbage where the available potassium in the soil was already high. It also depressed the magnesium content at/

at both centres and the phosphorus content at Downfield. This confirmation of the results obtained recently by other workers (p.15) is particularly important in regard to treatment of pastures. In recent years, there has been a tendency to improve pastures and grassland by application of fertilisers rich in nitrogen and potassium. This application of large amounts of potassium almost indiscriminately could be a significant factor in the occurrence of grass tetany and requires further work in relation to the optimum potassium - magnesium ratios in soils.

Treatment with the double salt was found to depress the calcium and phosphorus contents of the herbage, but to raise the magnesium content slightly. It does not appear that this salt is suitable for application to mixed herbage except perhaps where the soil is low in available potassium, since the magnesium content is raised more effectively by magnesium sulphate.

Table 10.

HERBAGE EXPERIMENTS

(c) Forteviot : New Mill Field

Plan

A 1	D 2	C 3	B 4	E 5	
B 10	C	E	D	A 6	
E 11	B	D	A	C 15	30 yds.
C 20	A	B	E	D 16	
D 21	E	A	C	B 25	

25 yds.

New Mill samples

Results : Soils

	Before treatment	Average rest of season
pH	6.7 - 7.1	
% Ca	0.15 - 0.17	0.16 - 0.17
% Mg	0.012 - 0.014	0.013 - 0.015
% P	0.022 - 0.025 (H)	0.012 - 0.034 (M-H)
% K	0.021 - 0.026 (L-ML)	0.021 - 0.048 (L-M)

C3: New Mill field, Forteviot.

Soils. (Table 10).

The soils were neutral but lower in available calcium than those at Downfield and East Bank. During the season, the pH dropped slightly while the available calcium remained about the same. The available magnesium was lower than at Downfield but slightly higher than at East Bank. Treatment with potassium-magnesium sulphate and magnesium sulphate alone raised the available magnesium slightly during the season. The available potassium was high but the available phosphate was low to medium low.

Herbage. (Table 11 & App. Table 21).

The results for the third cut are average results of separate analyses; those for the remainder are results of single analyses of composite subsamples.

% Calcium.

The calcium in the original samples was very high as a result of the heavy liming. By the first cut in May, it had dropped considerably on all plots in spite of applications of "nitrochalk" by the farmer. Between the first and second cuts, the grass was cut by the farmer for dried grass and "nitrochalk" applied, during which time the calcium content rose to a value intermediate between that of the first cut and the original samples. Thereafter no more "nitrochalk" was applied and the calcium content of the herbage dropped gradually until September. By the final cut in December, it had/

Table 11.

New Mill samples

% Ca in D.M. original samples 1.14 - 1.31

Treatment	Cut 1	2	3	4	5	6
A	0.674	0.810	0.943	0.884	0.843	0.643
B	0.587	0.812	0.917	0.813	0.826	0.635
C	0.546	0.778	0.927	0.810		0.663
D	0.565	0.773	0;893	0.783		0.622
E	0.654	0.827	0.982	0.870		0.617
St. error	-	-	-	-	-	-
Sig.at 5%	-	-	-	-	-	-

% Mg in D.M.

A	0.265	0.322	0.316	0.273	0.272	0.243
B	0.240	0.314	0.320	0.290	0.277	0.216
C	0.250	0.322	0.310	0.309	0.300	0.238
D	0.236	0.298	0.293	0.277	0.278	0.207
E	0.242	0.310	0.314	0.315	0.302	0.219
St. error	-	-	4.22	-	-	-
Sig.at 5%	-	-	0.033	-	-	-

had fallen to the May level.

<u>% Magnesium</u>.

The magnesium content of the herbage was initially about the same as that at Downfield in spite of the fact that the soils were lower in available magnesium. By the first cut in May, the magnesium content of the herbage had risen considerably, and continued to rise until the second cut in June after which it fell steadily until September, remaining throughout the season considerably higher than that of herbage at either Downfield or East Bank.

The sudden rise in magnesium content prior to the first cut corresponded to the application of large amounts of "nitrochalk" by the farmer. A similar effect was observed at Boghall on applying "nitrochalk" to cocksfoot and ryegrass, so it is probable that the rise was due to the fertiliser here. When the "nitrochalk" was stopped in August the magnesium content dropped again.

Application of "nitrochalk" could have various effects on the mineral content of plants depending on the conditions existing in the soil. (1) The addition of calcium ions in the "nitrochalk" might raise the concentration of calcium ions in the soil solution to such an extent that the absorption of magnesium by the plant would be depressed. (2) The calcium ions might displace magnesium ions in the soil complex, thus releasing magnesium to the soil solution for absorption by the plant.

The reaction taking place will depend on several factors, the/

the most important being the ion ratios in the soil.

Effect of Treatments.

It was not possible to determine the significant differences in the first and second cuts, as the samples were composite subsamples. In the third cut, none of the differences was significant. It was however possible to see a general trend in some treatments although the effects had obviously been considerably upset by the heavy dressings of "nitrochalk".

The difference in seasonal variation in calcium and magnesium between the ryegrass at Boghall and the grass from this experiment, which was mainly ryegrass, is marked. In the latter, the changes were much less abrupt, and both the calcium and magnesium contents were considerably higher, both effects due to the applications of "nitrochalk".

1. Magnesium sulphate (E)

% Calcium.

Treatment with magnesium sulphate appeared to depress the calcium content of the herbage in the first cut, but by the second cut, any effect had worn off.

% Magnesium.

In the first cut, the herbage treated with magnesium sulphate had a lower magnesium content than did the control herbage, but thereafter the magnesium content was about the same or slightly higher than that of the control. It appeared that the treatment had little effect, in spite of the fact that the available magnesium in the soils was low.

2./

2. Potassium sulphate (D)

% Calcium.

The calcium content of the herbage treated with potassium sulphate was lower than that of the control herbage throughout the season, but showed the same seasonal variation.

% Magnesium.

Treatment with potassium sulphate depressed the magnesium content in the first three cuts, although by the third cut there was no significant difference between the plots, and thereafter the effect wore off.

3. Potassium-Magnesium sulphate (B & C)

% Calcium.

Treatment with a single dose of the double salt had little effect on the calcium content of the herbage in the first cut, but the double dose depressed the calcium content considerably. By the second cut, the treated plots were both lower than the control and remained so throughout the season. The depressing effect was less pronounced however than that of the potassium sulphate.

% Magnesium.

Treatment with the double salt appeared to have little effect on the magnesium content, contrary to results from the hay plots at Downfield and East Bank.

Discussion.

The difference in mineral content between swards grown for hay and cut for dried grass can be seen clearly from these results./

results. The mineral content of grass tended to drop as it grew towards the hay stage, whereas grass which was cut monthly or six-weekly and not allowed to reach maturity showed a considerable variation in mineral content.

The effect of treatments other than potassium sulphate was slight, probably because of the heavy dressings of "nitrochalk". Potassium sulphate was found to have the same effect at Downfield and East Bank - depression of calcium and magnesium.

Conclusions

The results obtained from grass and herbage experiments show that the mineral content of a mixed sward will depend on several factors:

(a) the available nutrients in the soil.

(b) the botanical composition of the herbage.

(d) the frequency of cutting or grazing.

(c) the time of sampling.

(e) the fertilizer treatment.

A. The available nutrients in the soil.

The amounts of available calcium and phosphorus were similar and fairly high in the soils examined. The available magnesium however varied considerably between Downfield and East Bank, and it was found that where the soils were low in available magnesium, the magnesium content of the herbage was also low.

B. The Botanical Composition.

The mineral content of grasses varied from species to species as was shown by the results from Boghall. Danish cocksfoot, for example, was richer in calcium than Ayrshire ryegrass, but lower in magnesium ~~or~~ & phosphorus. The clovers tended to be richer in calcium and magnesium than the grasses. The mineral content of a sward will therefore depend on the number and proportion of the different species present, swards with a high proportion of clover tending to be richer in minerals than swards low in clover.

C./

C. The time of sampling.

It was found that the mineral content of most grasses and clovers showed a considerable seasonal variation, from month to month throughout the year. Ayrshire ryegrass, for example, showed the following change,

	% Ca	% Mg	% P
1st Cut	0.47	0.15	0.44
6th Cut	0.65	0.17	0.64

while herbage from East Bank varied during the season from 0.64 to 0.48% Ca and from 0.17 to 0.11% Mg.

The values obtained for the mineral content of a sward will therefore depend to a large extent on the period during the year in which the samples are taken. An isolated sample could give a false impression of the mineral status of a sward unless this is borne in mind. Generally, the mineral content of grass which was cut monthly was higher at the end of the season than at the beginning.

D. The frequency of cutting.

The results obtained from experiments with grass cut at monthly intervals (A_1 and A_2), grass allowed to grow until September before cutting (B) and mixed herbage grown for hay ($C_{1,2}$) showed that the frequency with which a sward is cut will affect very greatly the seasonal variation in mineral content. Several authors have already found that as grass matures, the nutritional value decreases, and this was borne out by the results from mixed herbage grown for hay at Downfield and East Bank. The fresh young growth after the hay/

hay had a considerably higher mineral content than the hay. In grass which was cut at monthly intervals, the mineral content of consecutive samples changed more suddenly than did that of grass which was allowed to mature.

This aspect is important in relation to the grazing and feeding of animals. Pastures which are grazed fairly frequently and where the grass is not allowed to reach maturity will tend to be richer in minerals than those which are left ungrazed. Hay tends to have a low mineral content and so some other form of minerals should be provided, particularly with stall-fed animals. This is particularly important in relation to "magnesium tetany".

E. The fertiliser treatment.

The results obtained with various fertilisers studied indicated that the effect of a fertiliser will depend not only on the fertiliser itself but on the mineral status of the soil to which it is applied and the cation-anion ratios

"Nitrochalk" increased the calcium and magnesium contents of grasses cut monthly or six-weekly, but the effect on the clover seemed to vary depending on the grass with which it was grown. Repeated applications of "nitrochalk" tended to reduce the clover content of the sward with a consequent reduction in the mineral content of the sward.

Magnesium sulphate raised the magnesium content of herbage, particularly where the soil was low in available magnesium,/

magnesium, which agrees with the results of other workers. Application of magnesium sulphate to herbage can therefore be recommended particularly early in the season when the magnesium content of the herbage is low.

Potassium sulphate was found to depress the magnesium and phosphorus contents of herbage, and where the soil potassium was already high, the calcium content was depressed also. The results show that potassium salts should be applied with discrimination since the application of large amounts will seriously reduce the content of other minerals, in particular, magnesium, and could be a contributory factor to "grass tetany".

Potassium magnesium sulphate, however, could be applied without reducing the magnesium content of the herbage and would therefore be more suitable for use than potassium sulphate.

The uptake of minerals from a sward is considerable and again varies from species to species. Application of fertilisers such as "nitrochalk" affect the yield and therefore the uptake of other elements than calcium. This increase in uptake may be considerable as in the case of magnesium and should be taken into account when considering replacement of the minerals in the soil in subsequent applications of fertilisers.

TURNIP EXPERIMENTS

(a) Downfield

Plan

B 7	C 8	A 9
C 4	A 5	B 6
A 1	B 2	C 3

Area: each plot 6 x 17 sq. yrds.
total area 18 x 51 sq. yrds.
area sampled 20 x 9 sq. ft.

(b) Luthrie

Plan

A 7	C 8	B 9
C 6	B 5	A 4
B 1	A 2	C 3

Area: each plot 6 x 20 sq. yrds.
total area 18 x 60 sq. yrds.
area sampled 20 x 9 sq. ft.

Turnip Experiments

To investigate the effect of K_2SO_4; $MgSO_4$ (double salt) on the yield and Mg content of turnips.

Centres: Downfield and Lower Luthrie Farms.

Treatments (see plan opposite)

All plots received 5 cwt/acre Ammonium sulphate

5 cwt/acre Superphosphate

Individual plots

A : Control : no treatment

B : K_1 Mg_1 : 2 cwt/acre K_2SO_4; $MgSO_4$

C : K_2 Mg_2 : 4 cwt/acre " "

Plots laid down : March 1953.

" harvested : November 1953.

Collection of Samples.

Turnips: An area of 20 sq. yds (20 x 9 sq.ft.) was measured in the centre of each plot, and the turnips in that area were sampled. A core was taken from every second turnip and a leaf sample from every turnip.

After sampling, the turnips in the measured area were lifted and topped, and the tops and roots were weighed.

Treatment of samples: The cores were transported to the laboratory in tins, and the leaves in bags, and both the leaves and cores were weighed and dried, the cores at 80°C and the leaves at 100°C.

Soils: A sample of soil was taken from each plot before the treatments were applied and at the time of sampling.

Analyses/

Table 12.

Turnip Experiments

Results: soils.

Downfield

	pH	% Ca	% Mg	% P	% K
April A	6.2 - 7.1	o.27	0.015	.057 - .070	> 4.2 (VH)
B	6.5 - 7.2	0.29	0.015	.047 - .061	> 4.2 (")
C	6.5 - 7.3	0.29	0.019	.065	1.9 - 4.2 (M-H)
Nov. A	6.5 - 6.9	0.28	0.017	.078 - .122	1.2 - 2.2 (M-H)
B	6.3 - 7.0	0.29	0.016	.078 - .113	2.0 - 2.8 (")
C	6.3 - 7.3	0.31	0.021	.087 - .113	1.0 - 1.7 (ML-M)

Luthrie

	pH	% Ca	% Mg	% P	% K
April A	5.6 - 5.8	0.23	0.030	.044 - .065	> 4 (VH)
B	5.7 - 5.9	0.37	0.048	.004 - .061	> 4 (")
C	5.7 - 5.8	0.34	0.037	.061 - .065	3.2 - 4 (H)
Nov. A	6.7 - 7.0	0.32	0.027	.087 - .105	1.9 - 2.2 (M-H)
B	6.6 - 7.0	0.29	0.030	.113 - .122	1.9 - 2.3 (M-H)
C	6.6 - 6.9	0.32	0.047	.105 - .113	2.1 - 4.0 (")

Analyses

The cores and leaves were ashed and the calcium and magnesium contents determined (see p. 42) The soils were treated as on p.43-4 for the estimations of pH and available K, P, Ca and Mg.

Results

Soils: (Table 12)

Downfield: The soil was neutral, high in available potassium and calcium, but low in available magnesium. Plots C were slightly lower in available potassium than the other plots. After treatment and growth of the turnips, it was found that the potassium had dropped to about half its original value on all plots, while the phosphorus had increased considerably. The available calcium and magnesium remained about the same.

Luthrie: The soil pH was slightly lower than at Downfield and increased during the season. The soil was high in available potassium, and reasonably high in available phosphorus and calcium. The available magnesium was higher than at Downfield. Again the C plots were lower in available potassium than the others. By November, the potassium had again dropped to half value while the phosphorus rose. The available calcium remained about the same while the magnesium dropped slightly on plots A and B and rose on plot C.

Turnips:/

Tomatoes (Appendix tables 13-15).

Dry Matter Yield (Table 13a). The yield of dry matter [illegible]

[illegible]

significant.

% Calcium (Table 13a). [illegible]

was considerably higher than that of the roots at both centres

about five times at Downfield and six times at [illegible].

The calcium content of the roots was slightly lower at

Downfield than at [illegible], although the available calcium in

the soil was about the same [illegible]

and/

Table 13a.

Turnip Experiments

Results

D.M. Yield (cwts/acre)

Treatment	Downfield Roots	Downfield Shaws	Downfield Total	Luthrie Roots	Luthrie Shaws	Luthrie Total
A	40.94	12.61	53.55	47.00	6.69	53.69
B	46.05	11.50	57.55	46.68	5.52	52.20
C	44.45	11.68	56.13	47.85	6.35	54.20
*St.error	3.64	7.46	3.29	7.29	14.07	-
sig. at 5%	±3.98	±2.23	±4.59	±8.58	±2.18	-

% Ca in D.M.

Treatment	Downfield Roots	Downfield Leaf	Downfield Total	Luthrie Roots	Luthrie Leaf	Luthrie Total
A	0.328	1.76	-	0.430	2.15	-
B	0.310	1.88	-	0.434	2.00	-
C	0.308	1.81	-	0.442	2.17	-
St. error	3.98	1.98		6.38	1.79	
sig. at 5%	± .031	±0.09		±0.070	±0.10	

Uptake of Ca (Cwts/acre)

Treatment	Downfield Roots	Downfield Leaf	Downfield Total	Luthrie Roots	Luthrie Leaf	Luthrie Total
A	0.131	0.223	0.354	0.201	0.145	0.346
B	0.143	0.215	0.358	0.201	0.111	0.312
C	0.137	0.211	0.348	0.211	0.136	0.346
St. error	8.57	1.14		7.01	14.73	
sig. at 5%	±.030	±.0064		±.036	±.048	
" " 1%	-	±.0077		-		

* St. error: standard error of mean
sig. at 5%: significance at 5% level.

Turnips: (Appendix tables 22-24)

Dry Matter Yield (Table 13a) The yield of dry matter from the roots was of the same order of magnitude at the two centres, but that of the tops was much higher at Downfield than at Luthrie. At both centres, the yield of roots was greater than that of tops. The latter being about a quarter of the yield of roots at Downfield, and about an eighth at Luthrie.

Treatment with potassium magnesium sulphate increased the average dry matter yield of roots at Downfield, the smaller dressing being significant at the 1% level and the larger dressing at the 5% level. At Luthrie, the treatment had no significant effect on yield of roots.

The yield of tops appeared to be depressed slightly by the treatment at both centres, but the differences were not significant.

The total yield of tops and roots from the control plots was the same at both centres. Treatment appeared to have raised the total yield slightly at Downfield, but the differences were not significant.

% Calcium (Table 13a) The calcium content of the leaves was considerably higher than that of the roots at both centres about five times at Downfield and six times at Luthrie.

The calcium content of the roots was slightly lower at Downfield than at Luthrie, although the available calcium in the soil was about the same. Treatment with the double salt had/

Table 13b.

Results

% Mg in D.M.

Treatment	Downfield			Luthrie		
	Roots	Leaf	Total	Roots	Leaf	Total
A	0.093	0.207	-	0.122	0.370	-
B	0.089	0.200	-	0.126	0.343	-
C	0.091	0.216	-	0.129	0.373	-
St. error	3.3	4.8	-	2.63	4.12	-
Sig. at 5%	±0.008	±0.025	-	±0.008	±0.095	-

Uptake of Mg (cwts/acre)

Treatment	Downfield Roots	Downfield Leaf	Downfield Total	Luthrie Roots	Luthrie Leaf	Luthrie Total
A	.0381	.0262	.0643	.0570	.0244	.0814
B	.0408	.0231	.0640	.0585	.0186	.0772
C	.0405	.0254	.0659	.0615	.0229	.0844
St. error	6.00	12.1	5.84	8.24	13.31	7.05
Sig. at 5%	±0.0060	±0.0076	±0.0095	±0.0122	±0.0073	±0.0143

had no significant effect.

The leaves at Downfield had a considerably lower calcium content than those at Luthrie. It is possible that this might be due to the slightly lower soil pH at the former centre. Treatment with the doublt salt at the lower rate of application increased the calcium in the leaves at Downfield but depressed it at Luthrie. Treatment at the higher level of application had no significant effect at either centre.

Uptake of Calcium: The uptake of calcium by the leaves at Downfield was almost twice that of the roots, while at Luthrie it was considerably less.

The uptake of calcium by the roots was less at Downfield than at Luthrie. Treatment with the double salt had no significant effect at either centre.

The calcium uptake of the leaves was greater at Downfield than at Luthrie. Treatment with the double salt depressed significantly the uptake by the leaves at Downfield. At Luthrie, the effect was similar, but the differences were not significant.

The total amount of calcium removed from the soil was about the same at the two places, the differences in yield and calcium content being balanced out. Treatment had no significant effect on the total uptake of calcium.

% Magnesium: (Table 36) The magnesium content of the leaves was considerably higher than that of the roots at both centres - twice that of the roots at Downfield and three times that/

that at Luthrie.

The magnesium content of the roots at Downfield was much lower than at Luthrie, which was to be expected since the soil magnesium was lower. Treatment with the double salt had no significant effect but at Luthrie the treated roots were slightly higher in magnesium than the untreated.

The leaves at Downfield were also lower in magnesium than those at Luthrie, and again treatment with the double salt had no significant effect.

Uptake of Magnesium: The amount of magnesium removed by the roots at Luthrie was about $2\frac{1}{2}$ times that removed by the leaves, and at Downfield, the figure was almost twice that of the leaves, due in both cases to the higher yield of dry matter in the roots.

The uptake of magnesium by the roots was greater at Luthrie than at Downfield. Treatment with the double salt appeared to increase the uptake of magnesium by the roots at both sites. Although the differences were not significant.

The magnesium taken up by the leaves was about the same at the two centres, and was highest on the control plots although the differences were not significant.

The total amount of magnesium removed from the soil was greater at Luthrie, where the available soil magnesium was highest. Treatment at the high level of application increased the total uptake of magnesium at both centres, although the differences were not significant. On all plots, the amount of magnesium removed by the crop was less than the amount/

amount applied in the double salt.

Conclusions: The yield of turnip roots was considerably greater than that of tops, but appeared to be affected less by conditions of soil and climate. The differences between roots and tops at the two centres was balanced out in the total yield.

The mineral content of turnip leaves was much higher than that of the roots. The magnesium content of both roots and leaves appeared to depend directly on the amount of available magnesium in the soil, but the calcium content showed some variation unconnected with the available soil calcium at the two centres. This variation may have been due to the difference in pH in the two soils or to the different ion ratios.

The uptake of minerals from the soil was greater in the roots than in the leaves, except where the content of a particular element was especially high in the leaf, as in the case of the calcium at Downfield. The total amount of calcium or magnesium removed by the crop seemed to depend on the amount of the particular element available, but it was more difficult to draw conclusions with regard to the amounts removed by leaf or roots.

Treatment with potassium-magnesium sulphate increased the dry matter yield of roots where the available soil magnesium content was low. It had no effect on the magnesium content of roots or leaves, probably because of the presence of the potassium/

potassium, but it did affect the calcium content of the leaves and their uptake of calcium. At Downfield where the soil magnesium was low, the fertiliser increased the leaf calcium, but at Luthrie where the soil magnesium was higher, the leaf calcium was depressed. The fertiliser also had a depressing effect on the leaf uptake of calcium.

The use of potassium-magnesium sulphate for turnips could not really be recommended from these results. Although it increased the yield of roots where the soil magnesium was low, it is probable that a magnesium salt alone would be more effective. As regards mineral content of the turnips, the double salt would appear to have little value.

Table 14.

KALE EXPERIMENT

Forteviot

plan

9 C	8 B	7 A
4 A	5 C	6 B
3 B	2 A	1 C

Area - Each plot : 6 x 20 sq. yds.
Total area : 18 x 60 sq. yds.
Area Sampled : 3 x 7 sq. yds.

results: soils

		pH	% Ca	% Mg	% P	% K
April	A	7.1 - 7.4	0.32	0.015	.044 - .048	3.9 - 4.2 (H)
	B	7.0 - 7.4	0.27	0.014	.044 - .052	3.7 - 4.2 (H-VH)
	C	6.9 - 7.3	0.28	0.013	.039 - .044	3.2 - 4.2 (" ")
Nov.	A	7.0 - 7.6	0.24	0.012	.052 - .065	1.3 - 1.6 (M)
	B	6.8 - 7.4	0.22	0.014	.065 - .078	1.7 - 2.1 (")
	C	6.6 - 7.7	0.21	0.011	.052 - .070	1.5 - 1.7 (")

Kale Experiment

To investigate the effect of K_2SO_4, $MgSO_4$ (double salt) on the yield and Mg content of Marrow-stem kale.

Centre: Bankhead Farm, Forteviot.

Plan of Plots: see opposite.

Treatments

as for Turnip experiments (p. 98)

Plots laid down : March 1953

" harvested : November 1953

Collection of Samples.

Kale: An area of 21 sq. yds (3 x 7 sq. yds) was measured in the centre of each plot and the plants in that area were cut and weighed. Samples of leaf and stem were taken from every second plant.

The samples were transported to the laboratory in bags, dried at 100°C, milled and bottled.

Soils: A sample of soil was taken from each plot before the treatments were applied and at the time of sampling the plants.

Analyses

The stem and leaves were ashed and the Ca and Mg contents determined. (see p. 34, 41).

The soils were treated as on p. 34 and estimations made of pH, available K, P, Ca and Mg. (p. 43).

Table 15.

KALE EXPERIMENTS

Results : Kale

D.M. Yield (cwts/acre)

Treatment	Stem	Leaf	Total
A	34.39	10;98	45.37
B	36.67	11.93	48.60
C	36.70	11.92	48.62
St. error	5.11	2.64	47.53
Sig.at 5%	±4.58	±0.35	

% Ca in D.M.

A	0.739	1.556	-
B	0.778	1.532	-
C	0.758	1.314	-
St. error	2.48	11.67	-
Sig.at 5%	±0.047	±0.428	

Uptake of Ca

A	.2526	.1657	.422
B	.2833	.1807	.464
C	.2774	.1574	.435
St. error	11.01	11.25	8.28
Sig.at 5%	±0.0745	±0.0476	± .091

% Mg in D.M.

A	0.184	0.184	-
B	0.191	0.182	-
C	0.190	0.193	-
St. error	2.57	1.58	-
Sig.at 5%	±0.012	±0.003	

Uptake of Mg

A	.0627	.0203	.0830
B	.0699	.0217	.0916
C	.0699	.0230	.0929
St. error	8.23	1.96	.0892
Sig.at 5%	±0.00139	±0.0011	-

Results

Soils: (Table 14)

The soil was neutral, high in available potassium, reasonably high in available phosphorus and calcium, but low in available magnesium. By November, the available K had dropped to about half its original value, the Ca and Mg had dropped slightly, while the available P had risen.

Kale: (Table 15 & Appendix tables 25 & 26)

Yield There was no significant difference in total yield from any of the plots.

D.M. Yield Unfortunately the proportion of stem to leaf was not measured, but from results of kale experiments from previous years, it was found that the ratio of stem to leaf in singled marrow-stem kale was approx. 70 to 30. Assuming this figure, the dry matter yield of stem and leaf in cwt./acre was calculated. (This figure is only approximate as the percentage stem may vary from 60-80% but it gives a means of comparing the effect of treatment on stem and leaf.)

For both the stem and the leaf, the treated plots had a higher yield of dry matter than the control plot. In the former the differences were not significant but in the latter the treated plots were higher at the 1% level.

The total yield of dry matter was also higher from the treated plots.

It would appear therefore that treatment with the double salt increases the yield of leaf in kale but that there is little/

little difference between the two rates of application.

% Calcium: The calcium content of the leaf was approximately twice that of the stem. Treatment with the double salt appeared to have depressed slightly the calcium content of the leaves, while increasing it in the stems, but the differences were not great enough to be significant.

Uptake of Calcium: The uptake of calcium by the leaves was much less than by the stem because of the difference in yield between leaf and stem. The treatment appeared to have little effect on the uptake of calcium by either leaf or stem. It did increase the total uptake slightly but the differences were not significant.

% Magnesium: The magnesium content of the leaf was of the same order of magnitude as that of the stem. Treatment with the double salt had little effect on the magnesium content of the stem but at the higher rate of application, it increased significantly (1% level) the magnesium content of the leaf.

Uptake of Magnesium: The amount of magnesium removed from the soil by the leaf was about $\frac{1}{3}$ that of the stem. Treatment increased significantly the uptake of magnesium by the leaf, the higher rate of application being significantly more effective than the lower one. The uptake in stem was also greater on the treated plots but the differences were not significant.

The/

The total amount of magnesium removed by the kale plants was slightly increased by treatment but the increase was not significant and was less than the amount of magnesium applied in the form of the double salt.

Conclusions: The mineral content of the kale leaf was greater than that of the stem but the yield of dry matter was considerably less, so that the amount of calcium and magnesium taken up by the leaves was much less than that taken up by the stem.

Treatment with potassium-magnesium sulphate increased the magnesium content and the yield of the kale leaves and the uptake of magnesium by the leaves but had no significant effect on the stem. It would appear that the leaves show the first reaction to this fertiliser.

This increase in yield and magnesium content of the leaf is important with reference to the feeding of kale to cattle, particularly if the soil is low in available magnesium. The use of the potassium-magnesium sulphate for kale can therefore be recommended.

Summary.

The experiments with grass and clover at Boghall and ryegrass at Bush showed that:-

1. the mineral content of different species of grass and clover varied considerably, the clovers tending to be higher in mineral content than the grasses.

2. the mineral content of white clover was affected by the grass with which it was grown and the competition with the grass for the available nutrients, particularly in the case of phosphorus.

3. the mineral content of both grasses and clover varied considerably from month to month, the nature of the variation depending on the frequency of cutting. In grasses cut monthly, the mineral content tended to increase towards the end of the season, while in uncut ryegrass, the mineral content decreased as the grass matured.

4. treatment with "nitrochalk" increased the calcium and magnesium contents of grasses throughout the season, and increased the phosphorus content initially. The effect of treatment on the clover seemed to depend on the yield and leafiness of the grass with which it was grown and the consequent competition between the grass and clover.

5. treatment with heavy dressings of $MgSO_4.7H_2O$ increased the magnesium content of ryegrass throughout the season.

6. the uptake of minerals varied from species to species and from month to month throughout the season, the monthly variation/

variation generally following that of the yield. The uptake of minerals by clover was lower than that of the grasses because of the lower yield of the clover. The total seasonal uptakes of calcium and of phosphorus were greater than the uptake of magnesium.

7. treatment with "nitrochalk" increased the uptake of all three elements by both grass and clover.

The mineral content of a sward will therefore depend on the botanical composition of the sward, the frequency of cutting, the time of year and the fertiliser treatment.

The experiments with mixed herbage grown for hay and for dried grass bore out these results and showed that:-

1. the magnesium content of the herbage depended on the available magnesium in the soil.

2. the mineral content of herbage decreased with advancing maturity.

3. the effect of the fertilisers studied depended not only on the nature of the fertiliser but also on the mineral status of the soil to which it was applied and the existing cation: anion ratios.

(a) magnesium sulphate raised the magnesium content of the herbage, particularly where the soil was low in available magnesium.

(b) potassium sulphate depressed the magnesium and phsophorus contents of herbage and in some cases the calcium content also.

(c)/

(c) potassium-magnesium sulphate had little effect on the magnesium and phosphorus contents of herbage, and was therefore more suitable for use where the soil was low in available magnesium.

The experiments with turnips and kale showed that:-

1. the yield of dry matter and the uptake of minerals in the leaf was less than that of the roots in turnips and of the stem in kale.
2. the mineral content of the leaf was higher than that of the roots in turnips and of the stem in kale.
3. the magnesium content of turnip leaves depended on the available magnesium in the soil.
4. treatment with potassium-magnesium sulphate increased the dry matter yield of turnip roots where the available soil magnesium was low, and increased the yield of magnesium content of kale leaves, and the uptake of magnesium by the leaves.

Acknowledgements.

The author wishes to express her appreciation to Professor S. J. Watson and Dr. A. M. Smith for help and advice in planning the work. Dr. H. Tod for assistance in laying down the field experiments, Mr. K. Simpson for assistance in the soil analyses and other members of the Chemistry Department who have helped. Thanks are also due to the Advisory Botany Department who made available samples of grass and clover from Boghall and provided yield data.

The Edinburgh and East of Scotland
College of Agriculture.

January, 1957.

References.

1. Albrecht, W.A., Soil Sci. Sco. Amer. Proc., 1937, 2, 315.

2. Alten, F., Potash Rev., 1952, 19, 10.

3. Bartholomew, R.P., Ark. Agr. Exp. Sta. Bull. 1933, 289.

4a. Bartlett, S., N.I.R.D. Reading, Ann. Rep., 1951, 34.

b. " " " " " " 1952, 39.

c. " " " " " " 1953, 44.

5. Bartlett, S., Brown, B.B., & Foot, A.S., Brit. Vet. J. 1954, 110, 3.

6. Bernadini, L., & Portici, G.M., Atti. R. Acead. Naz. Lincii, 1909, 21(1), 357. (& see 29b).

7a. Boynton, D., & Compton, O.C., Proc. Amer. Soc. Hort. Sci., 1944, 45, 9.

b. Boynton, D., & Compton, O.C., Soil Sci., 1945, 59, 339.

8. Brouwer, E., Brit. Vet. J. 1952, 108, 123.

9a. Cheng, K.L. & Bray, R.H., Soil Sci. 1951, 72, 449.

b. Cheng, K.L., Melsted, S.W., & Bray, R.H., Soil Sci., 1953, 75, 37.

10. Connors, J.J., J. Amer. Water Works Assoc., 1950, 42(1), 33.

11. Colin, H., & Bougy, E., Compt. Rend. Acad. Sci. (Paris) 1943, 216, 167.

12a. Cooper, H.P., Soil Sci., 1945, 60, 107.

b. Cooper, H.P., Paden, W.R. & Garman, W.H., Soil Sci., 1947, 63, 27.

13. Daniel, H.H. J. Amer. Soc. Agron., 1935, 27, 922.

14. Dewan, M.L., & Hunter, A.S., Soil Sci., 1949, 68, 451.

15. Eckerson, S.H., Amer. J. Bot., 1929, 16, 852.

16. Evans, T.W., Welsh J. Agr., 1931, 7, 255.

17a. Fagan, T.W., Welsh J. Agri., 1929, 5, 99.

" " " " " 1928, 4, 92.

" " " " " 1936, 12, 136.

Fagan, T.W., Agr. Progress, 1931, 65.

b. Fagan, T.W., & Milton, W.E.J., Welsh J. Agr. 1931, 7, 246.

c. Fagan, T.W., & Jones, H.T., Welsh P.B. Sta., 1920, Series H, 3, 85.

d. Fagan, T.W., & Watkins, H.T., Welsh J. Agr. 1932, 8, 144.

18. Follet-Smith, R.R., Rept. Dept. Agr. Brit. Guiana.

19. Forster, W.A., Analyst, 1953, 78, 179.

20a. Fudge, B.R., Proc. Fla. State Hort. Soc., 1938, 51, 34.

b. " " " " " " " 1942, 55, 17.

21a. Garner, R.J. et al. Nature, 1949, 164, 458.

b. " " " 1950, 166, 614.

22. Garner, W.W. et al. J. Agr. Res., 1930 40, 145.

23. Gehrke, C.W., Affsprung, H.E., & Lee, Y.C., Res. Bull, 570, 1954, Agr. Expt. Sta. Missouri.

24. Graham, E.R., Missouri Agr. Expt. Sta. Bull. 1938, 288.

25. Hinkle, D.A., & Eisenmenger, W.S., Soil Sci., 1950, 70, 213.

26. Hoblyn, T.N., J. Pomol. & Hort. Sci., 1940, 18, 325.

27. Holmes, W., J. Agr. Sci. 1949, 39, 128.

28. Hunter, A.S., unpublished Doctor's thesis, 1942 (Rutger's Univ. Library, New Brunswick, N.J.)

29. Jacob, Dr. A.
(a) Magnesium ein Pflanzen - nährstoff, P.45, 213. (Deutscher Innen - und Auzenhandel Bergbau)
(b) Magnesia: der fünfte Pflanzenhauptnährstoffe, (F. Enke, Stuttgart, 1955).

30. Javillier, M., & Goudchaux, S., Ann. Agron. 1940, 10, 9.

31. Kellogg, C.E., J. Amer. Soc. Agron. 1931, 23, 494.

32. —

33. Krackenberger, H.F., & Peterson, W.J., Southern Coop. Series 1954 Bull. 36, 98.

34./

34. Loew, O., U.S. Dept. Agr. Bur. Plant Ind. Bull. 45.

35. Longnecker, T.C., ubpublished Doctor's thesis, 1941, (Rutger's Univ. Library, New Brunswick, N.J.)

36. Longstaff, W.H., & Graham, E.R., Soil Sci., 1951, 71, 167.

37. Mameli, E., Inst. Bot., Univ. Pavia, (Ser.2), 15, 151.

38. Mason, A.C., Analyst, 1952, 77, 529.

39. Moser, F., J. Amer. Soc. Agron. 1933, 25, 365.

40. Mulder, E.A., Landbou. Bur. der Ned. Stikst. Ind., Aug. 1951.

41. Neales, T.F., Nature, 1956, 177, 388.

42. Obenshain, S.S., Va. Acad. Sci. Proc., 1944, 74.

43. Obst, W., see 29b.

44. Olson, L.C. & Bledsoe, R.P., Ga. Agr. Exp. Sta. Bull. 1942, 222.

45. Orr, J.B., Minerals in Pastures & their Relation to Animal Nutrition, 1929 (Lewis & Co.)

46. Piper, C.S., Soil and Plant Analysis. Adelaide, 1942.

47. Prince, A.L., Zimmerman, M., & Bear, F.E., Soil Sci., 1947, 63, 69.

48. Private Communication, Ferguson, W.S.

49. Reed, H.W., & Haas, A.R.C., Calif. Agr. Expt. Sta. Tech. Paper, 1924, 17, 1.

50a. Reith, J.W.S., Empire J. Expt. Agr., 1954, 22, 305.

b. Reith, J.W.S., & Williams, E.G., Empire J. Expt. Agr., 1949, 17, 265.

51. Scharrer, K., & Schreiber, R. see no. 29a. p.115, 105, 69.

52a. Schwarzenbach, G., & Ackermann, H., Helv. Chim. Aeta. 1947, 30, 1798.

b. Schwarzenbach, G., & Biedermann, W. Helv. Chim. Aeta., 1948, 31, 331, 678, 1029.

c. Schwarzenbach, G., & Biedermann, W. Chimia, 1948, 2, 56.

d. Schwarzenbach, G., et al., Analyst, Chim. Aeta., 1952, 7, 141.

53./

53. Shive, J.W., Physiol. Res., 1916, 1, 327.

54. Sjollema, B., & Seekles, L., Tijdschr. v. Diergeneesk., 56, 979.

55. Smith, H.W., et al., Soil Sci., 1949, 68, 401.

56. Stapledon, R.G., Welsh P.B. Sta. 1920, Series H. 3, 11.

57a. Stewart J., Scottish Agriculture, 1954, 34(2), 68.

b. " " Brit. Cattle Breeders' Club, Bull. 8/53. (Summer Course, Royal Agr. Coll. Cirencester)

58. Stewart, A.B., & Holmes, W., J. Sci. Food & Agr., 1953, 4, 401.

59a. Thomas, B., Thomson, A., et al., Empire J. Expt. Agr., 1952, 20, 10.

b. Thomas, B., Holmes, W.B., & Clapperton, J.C., Empire J. Expt. Agr., 1955, 90, 101.

60. Truog, E., Goates, R.J., et al. Soil Sci. 1947, 63, 19.

61. van Koot, Y., & Pattje, D.J., Tijdschr. Plantenziekten, 1942, 48, 121.

62a. Wallace, T., Agr. Review, 1956, March.

b. Wallace, A., & Ashcroft, R.T., Agron. J. 1956, 48, 219.

c. Wallace, T., Croxhall, H.E., & Pickford, P.T.H., Agr. Hort. Res. Sta. Long Ashton, Ann. Rep. 1942, 38.

63a. Walsh, T., & Clarke, E.J., Proc. Roy. Irish Acad., 1945, 50B, 245.

b. Walsh, T., & O'Donohoe, T.F., J. Agri. Sci., 1945, 35, 254.

64. Webb, J.R., Ohlrogge, A.J. & Barber, S.A., Soil Sci. Soc. Amer. Proc. 1954, 18(4), 458.

64a. Wheeler & Hartwell,

65. Willstätter, R., Ztschr. Physiol. Chem., 1909, 58, 438.

66. Williams, R.D., & Evans, T.W., Welsh J. Agr., 1932, 8, 151.

67. Willson, A.E., Anal. Chem., 1950, 22, 1571.

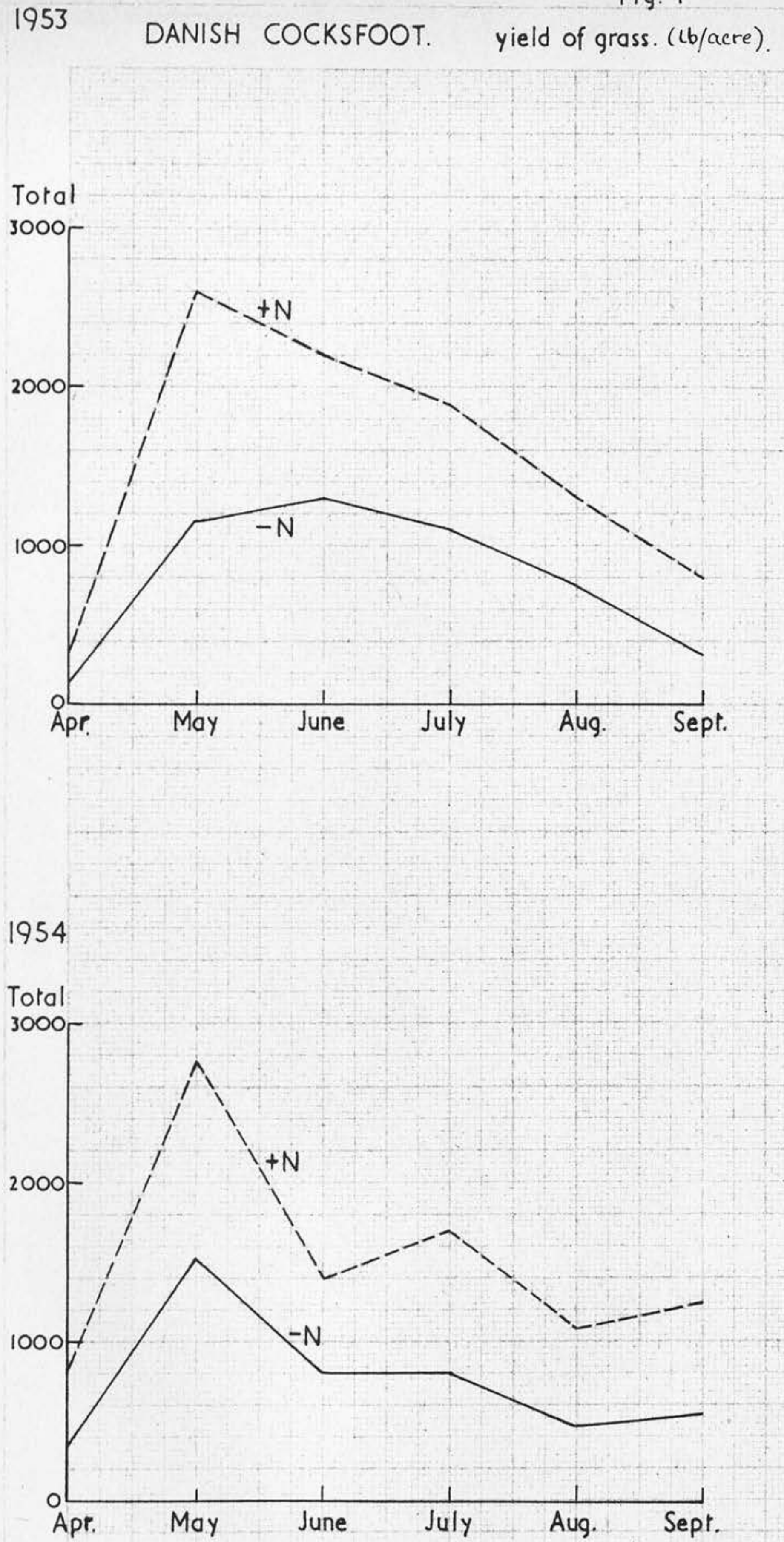
68. Willis, L.G., Pilland, J.B. & Gay, P.L., J. Amer. Soc. Agron. 1934, 26, 419.

69./

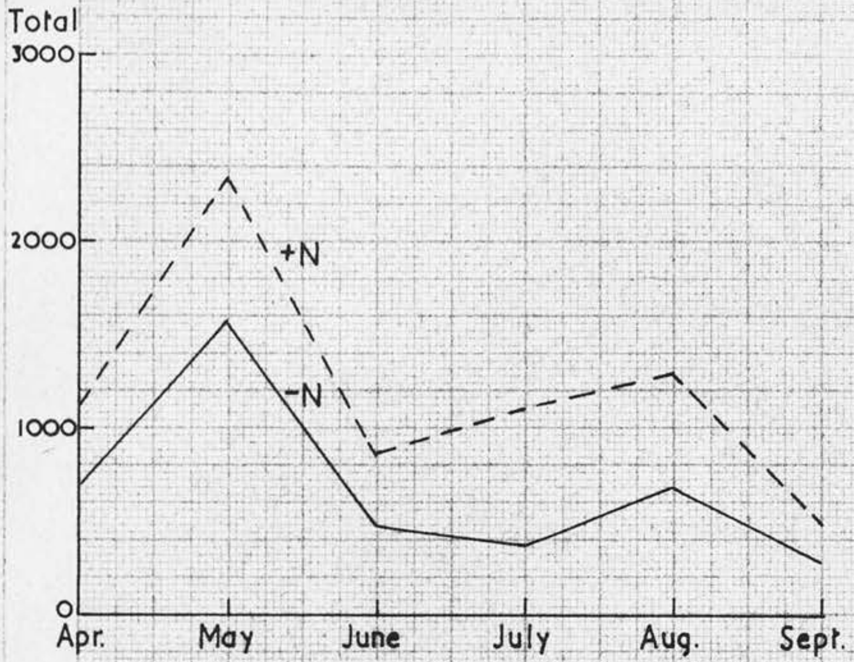
69. Wilson, M., Noble, M., & Gray, E.G., Trans. Roy. Soc., Edin., 1945, 61(2), 49.

70. Zimmerman, M., Soil Sci. 1947, 63, 1. (and unpublished Doctor's thesis, 1946)

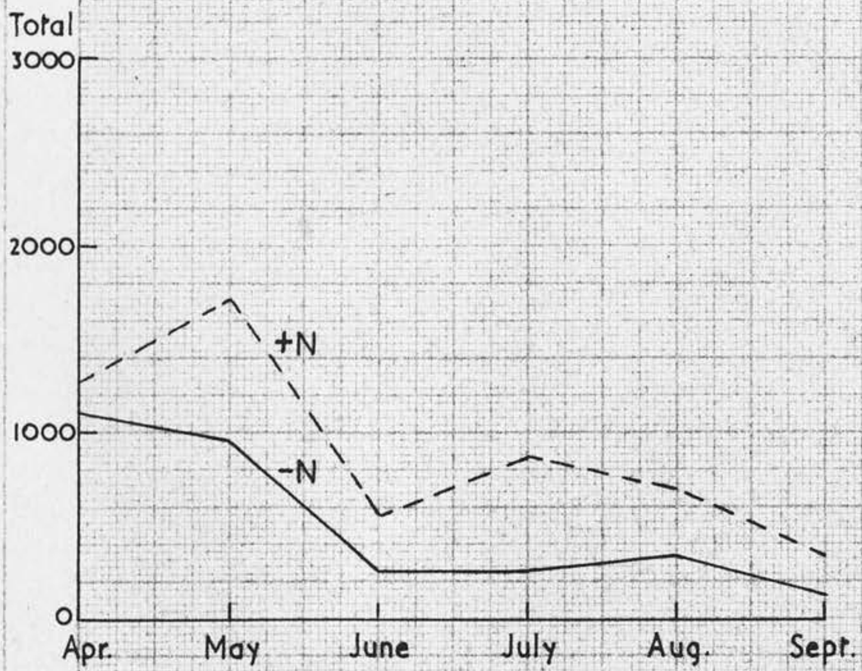
Fig. 1


1953
DANISH COCKSFOOT. yield of grass. (lb/acre).
Total
3000
2000
1000
0
+N
−N
Apr.
May
June
July
Aug.
Sept.
1954
Total
3000
2000
1000
0
+N
−N
Apr.
May
June
July
Aug.
Sept.

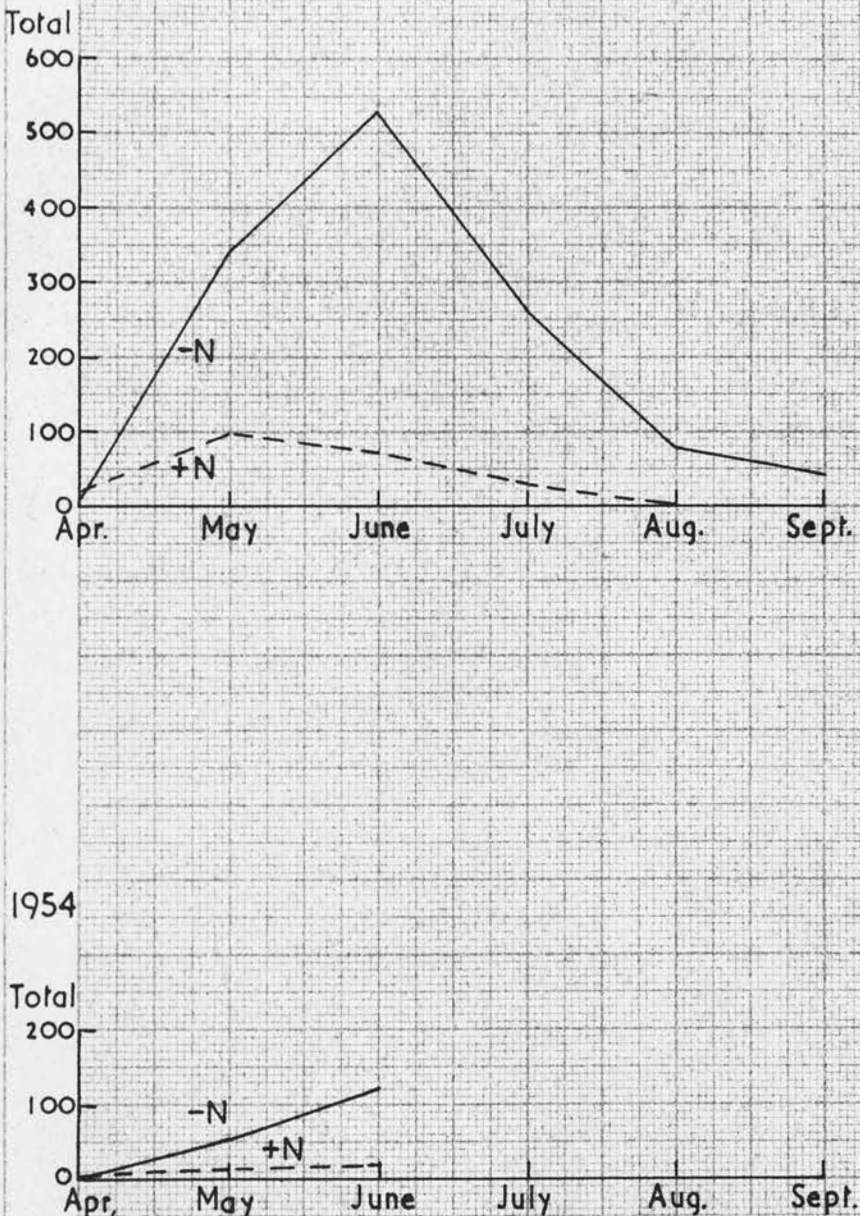
1953 AYRSHIRE RYEGRASS. yield of grass Fig. 2



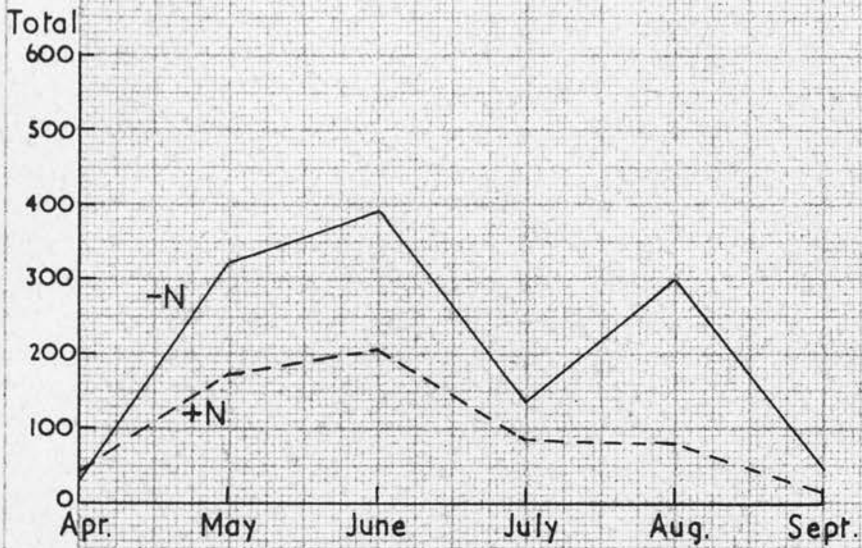
1954



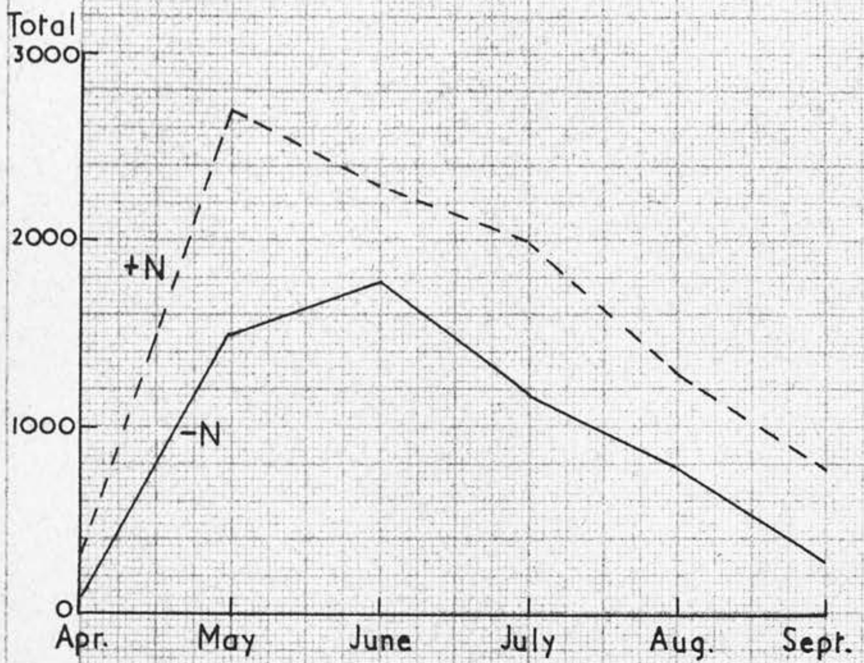
1953 WHITE CLOVER. yield of clover (D. C. plots) Fig. 3



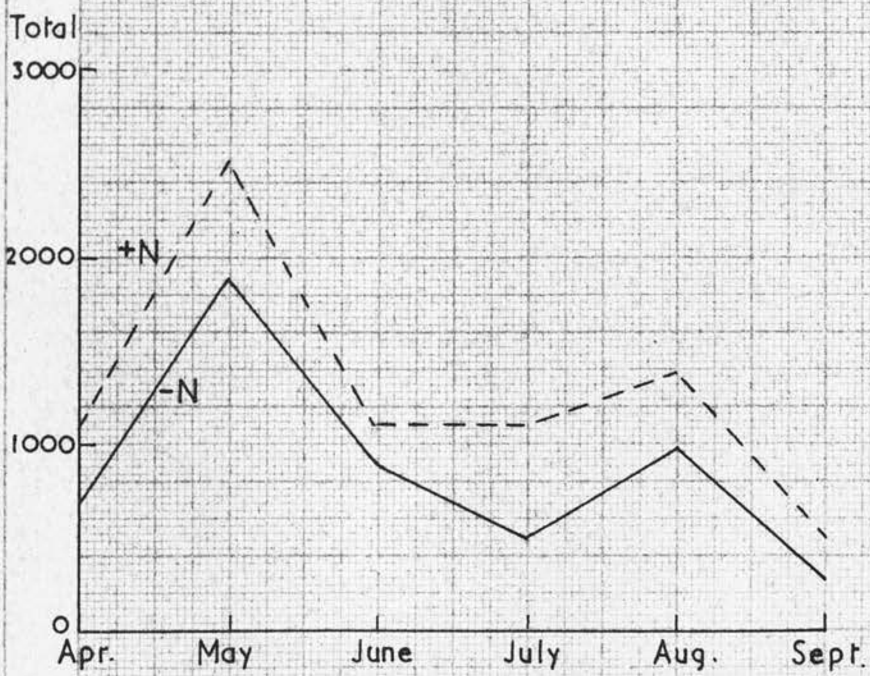
1953 WHITE CLOVER (A.R. plots) Fig. 4
yield of clover



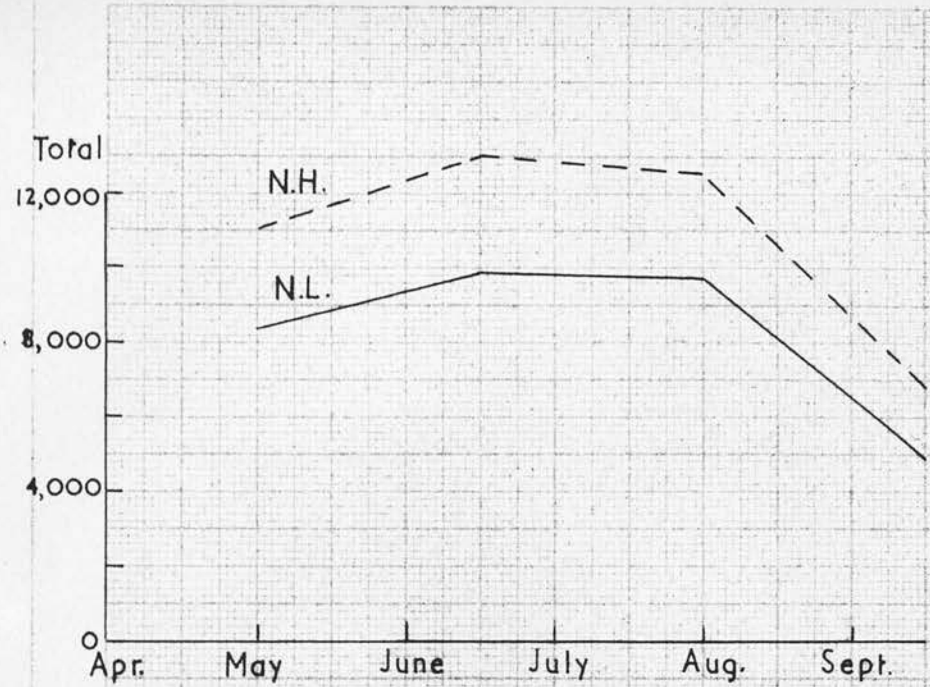
DANISH COCKSFOOT & WHITE CLOVER. Fig. 5
yield of grass and clover



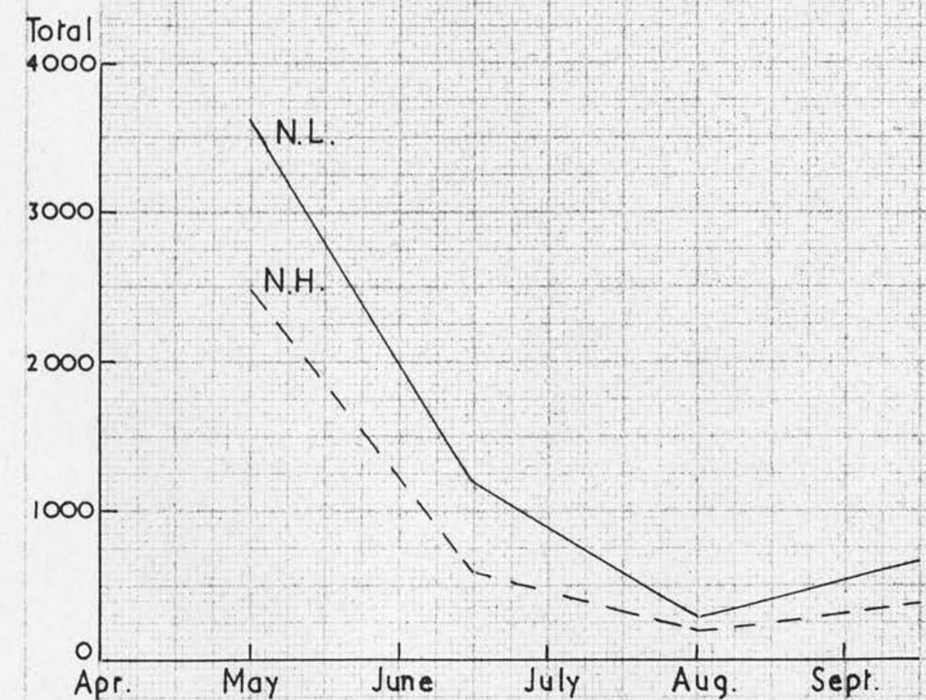
AYRSHIRE RYEGRASS & WHITE CLOVER. Fig. 6
yield of grass and clover



ITALIAN RYEGRASS yield of grass Fig. 7



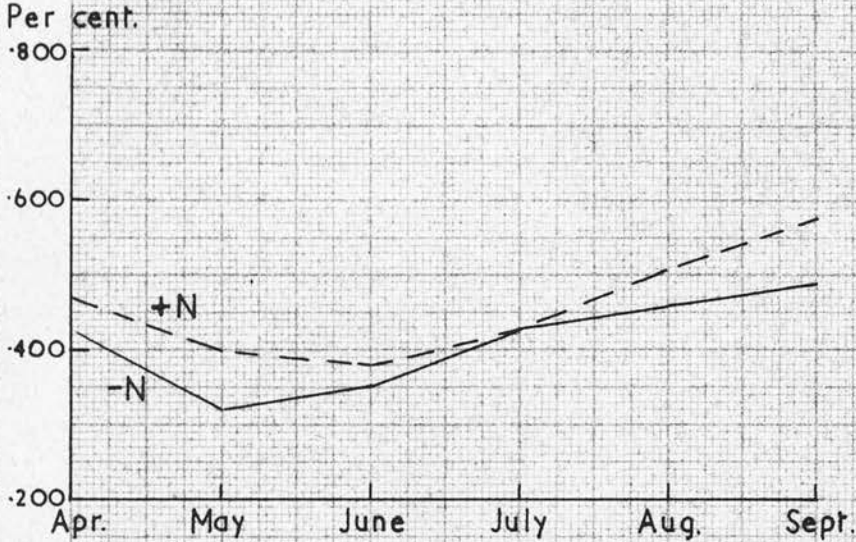
RED CLOVER yield of clover Fig. 8



1953

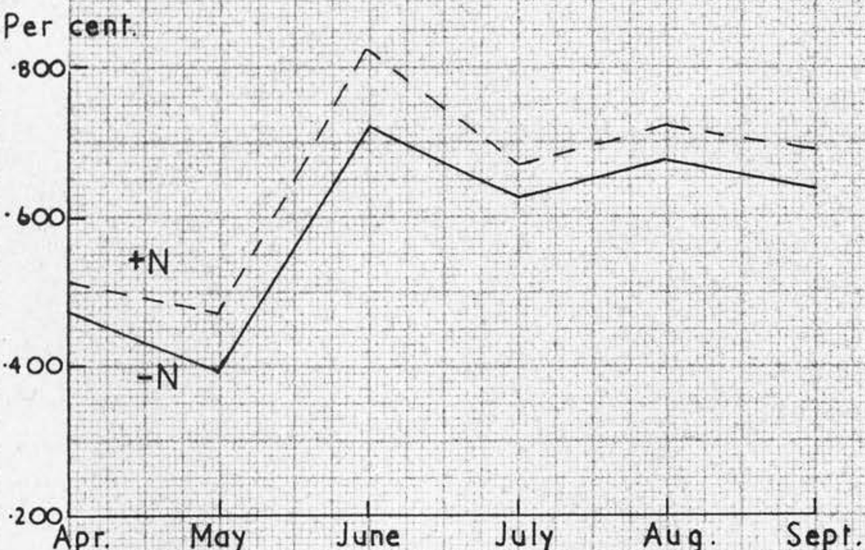
DANISH COCKSFOOT. Calcium

Fig. 9



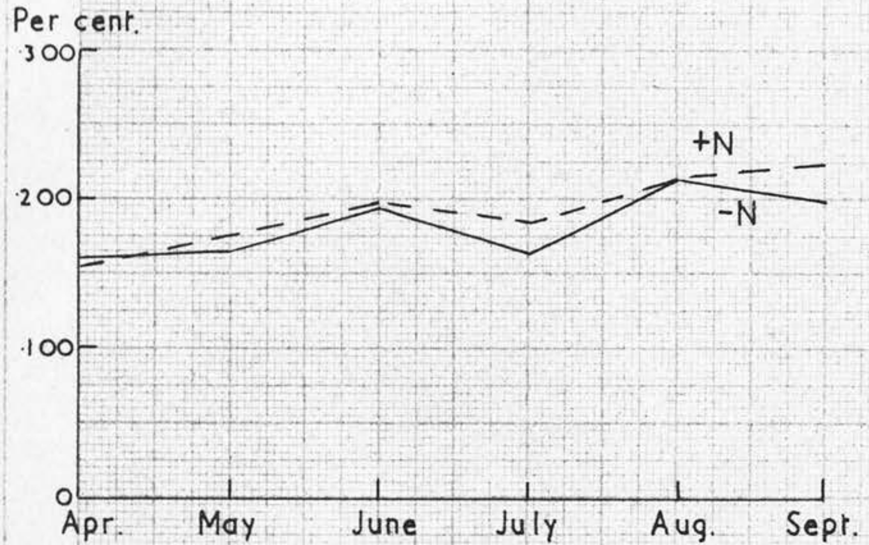
AYRSHIRE RYEGRASS. Calcium

Fig. 10



DANISH COCKSFOOT. Magnesium

Fig. 11



AYRSHIRE RYEGRASS. Magnesium

Fig. 12

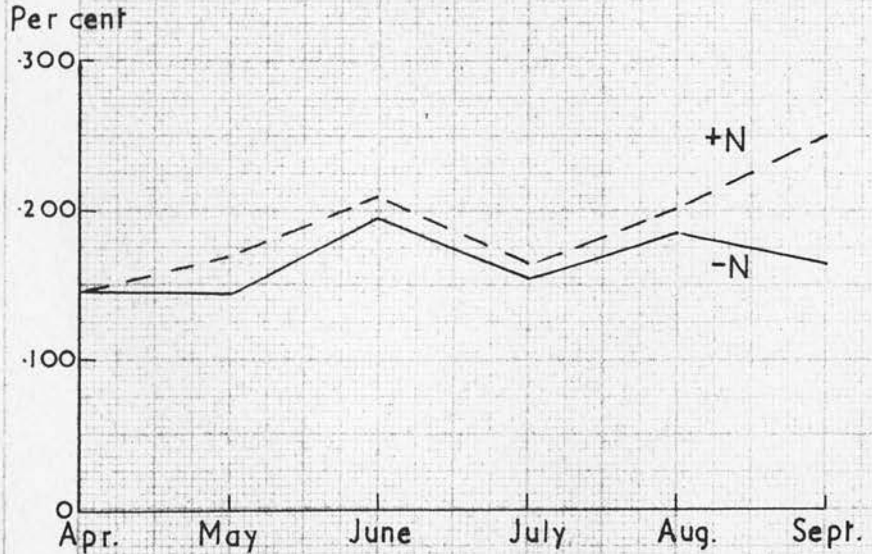


Fig. 13

DANISH COCKSFOOT. Phosphorus

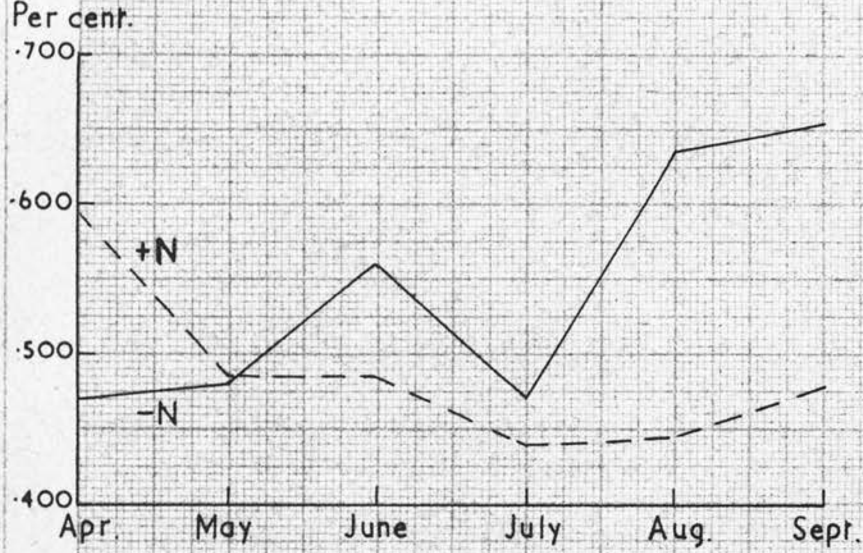
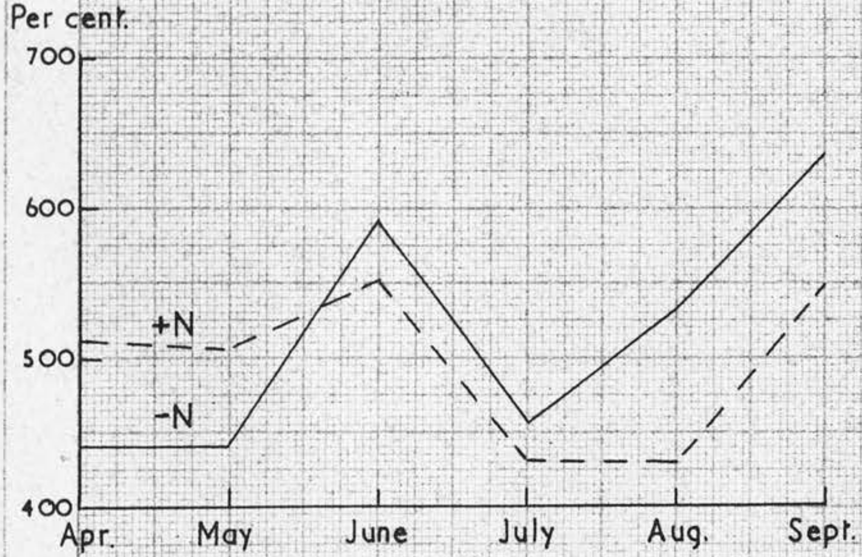
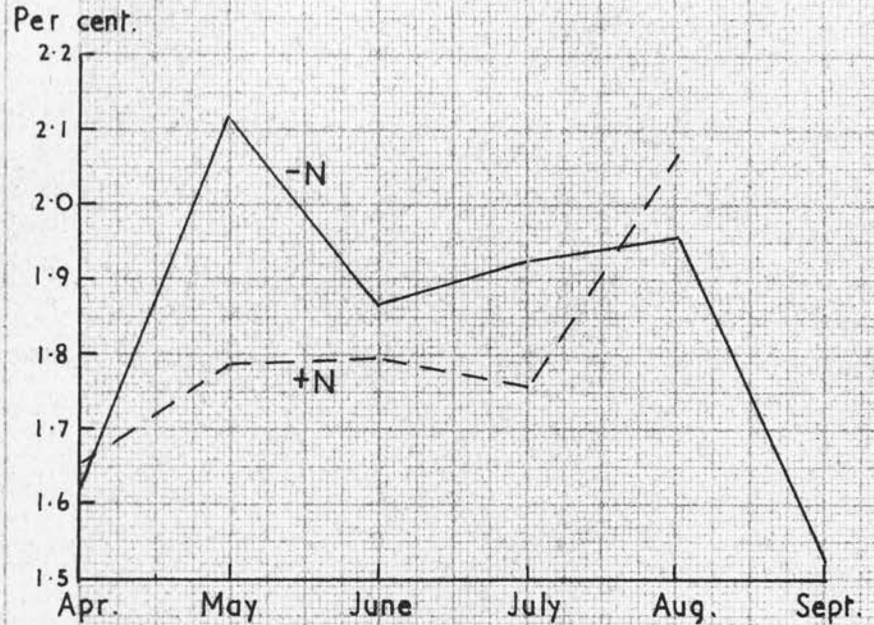


Fig. 14

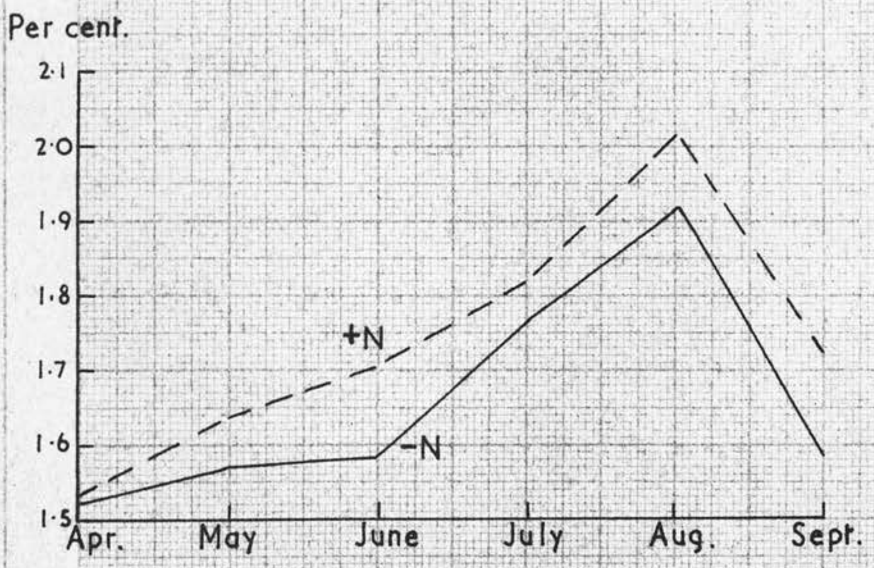
AYRSHIRE RYEGRASS. Phosphorus

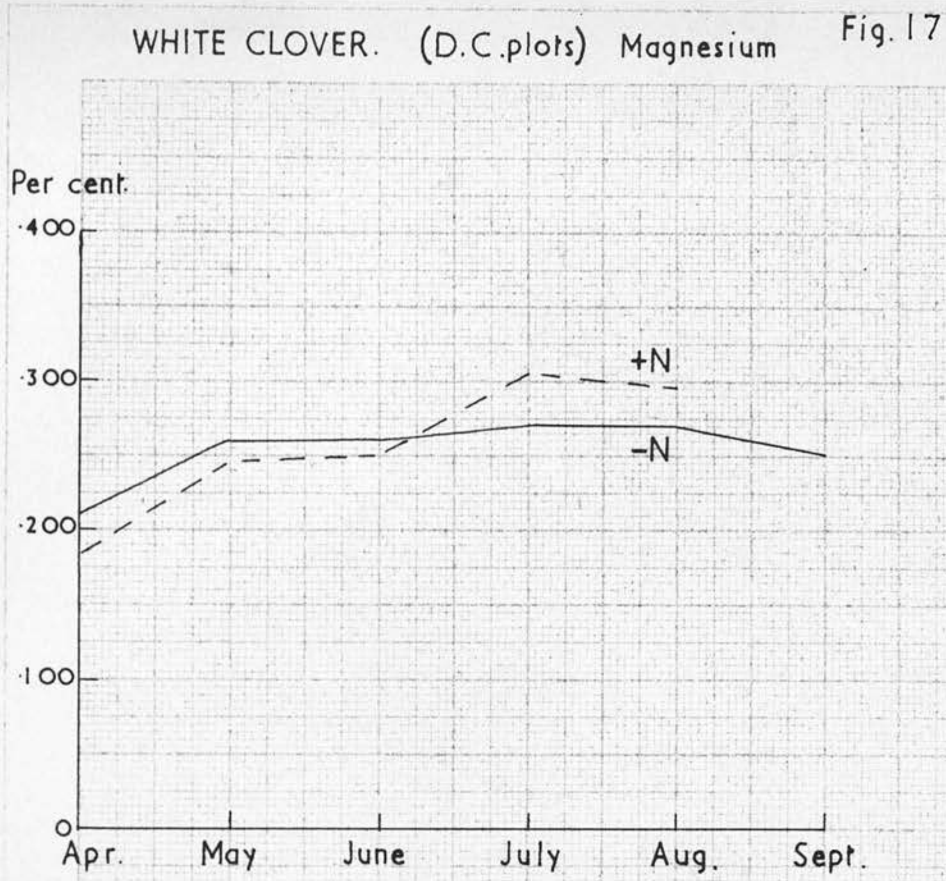


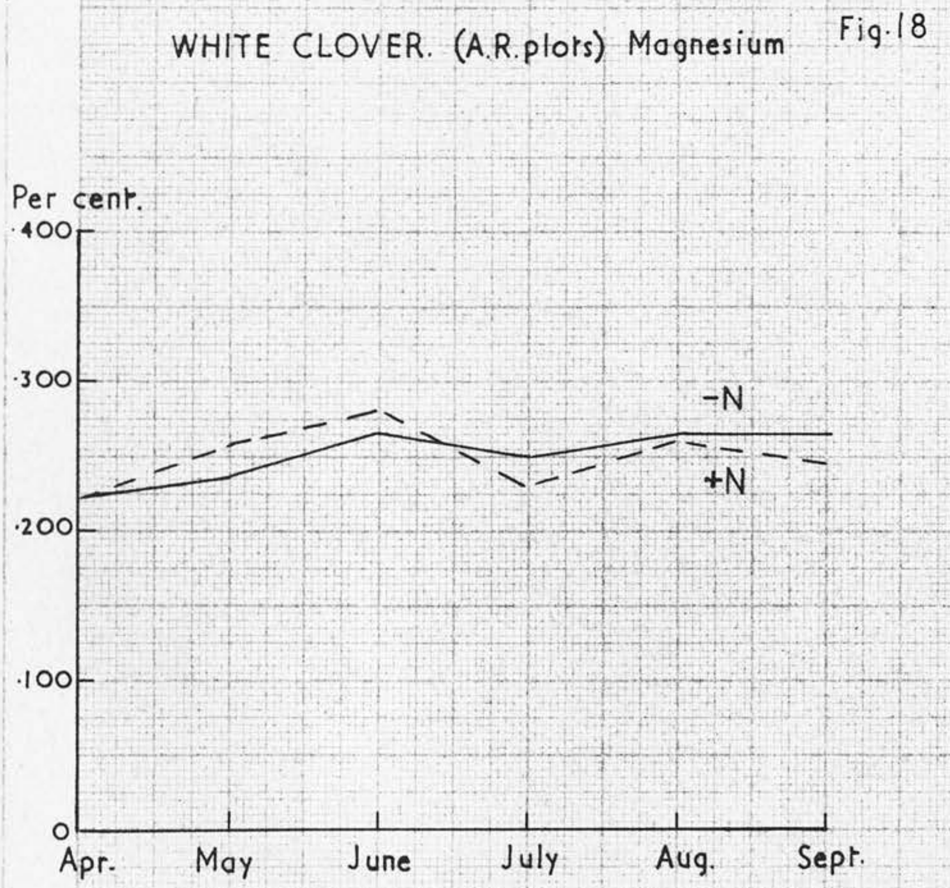
WHITE CLOVER. (D.C. plots) Calcium Fig. 15



WHITE CLOVER. (A.R. plots) Calcium Fig. 16

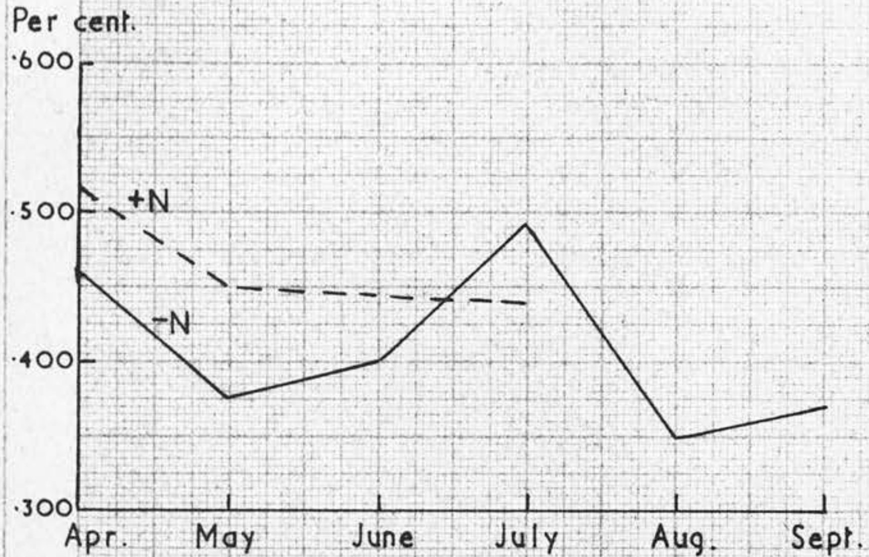



WHITE CLOVER. (D.C.plots) Magnesium
Fig. 17
Per cent.
·400
·300
·200
·100
0
+N
-N
Apr.
May
June
July
Aug.
Sept.


WHITE CLOVER. (A.R.plots) Magnesium
Fig. 18
Per cent.
·400
·300
·200
·100
0
-N
+N
Apr.
May
June
July
Aug.
Sept.

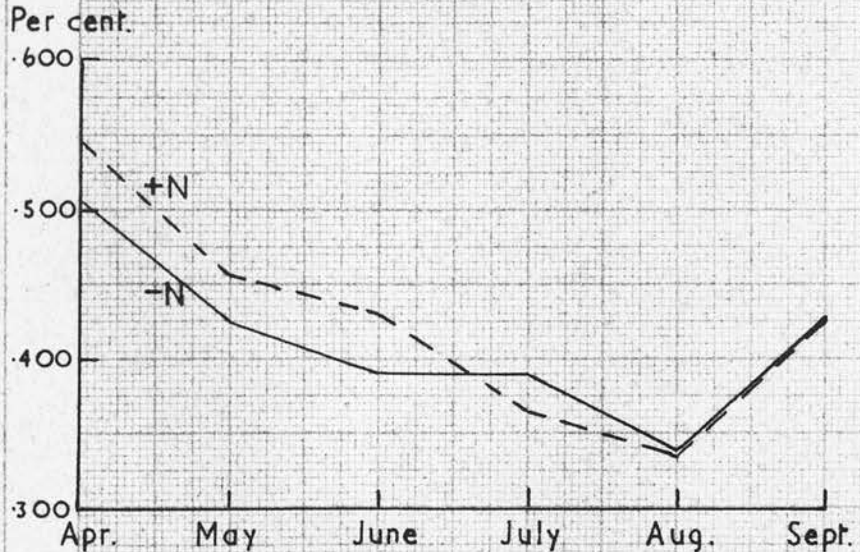
WHITE CLOVER. (D. C. plots) Phosphorus

Fig. 19

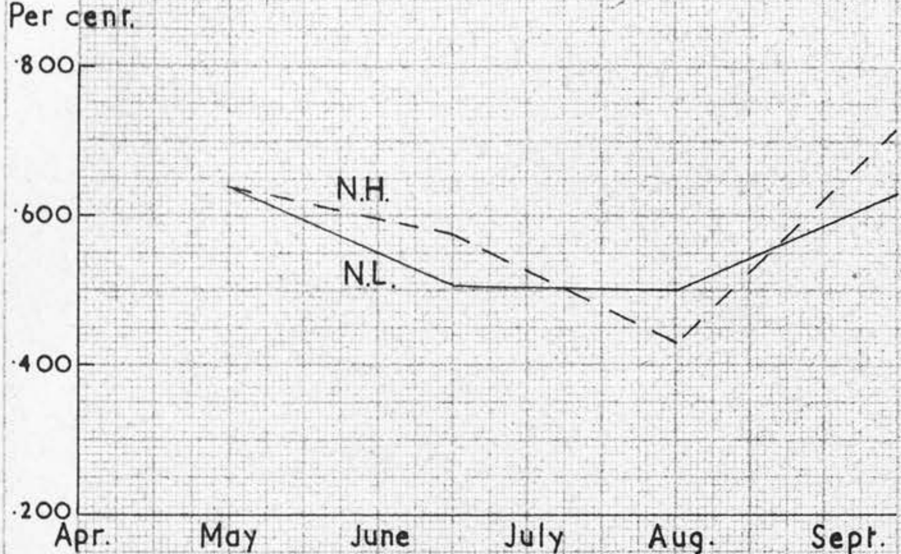


WHITE CLOVER. (A.R. plots) Phosphorus

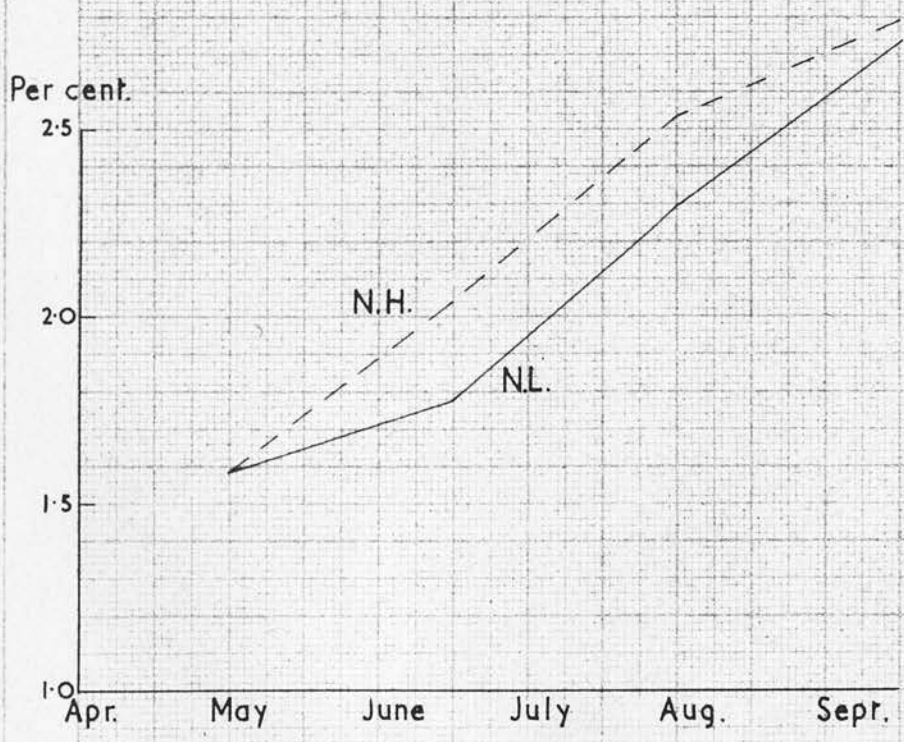
Fig. 20



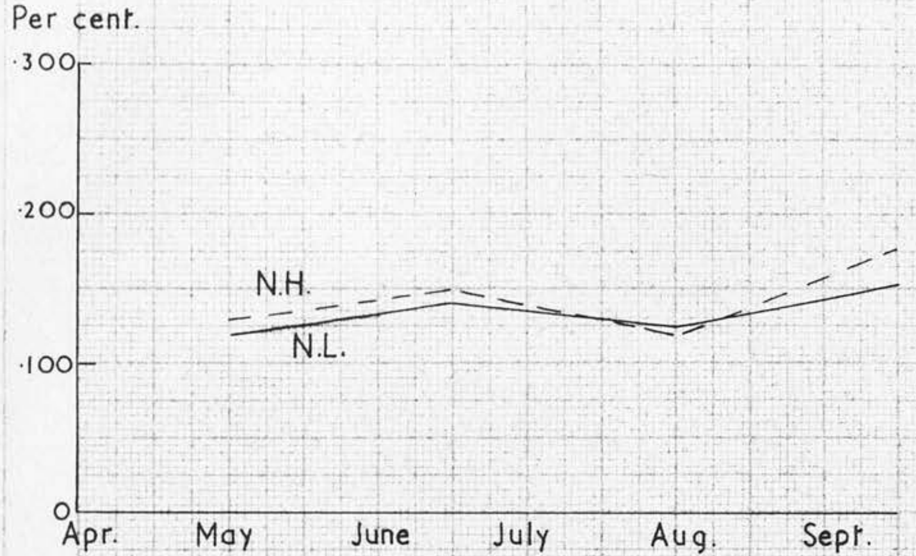
ITALIAN RYEGRASS. Calcium . Fig. 21



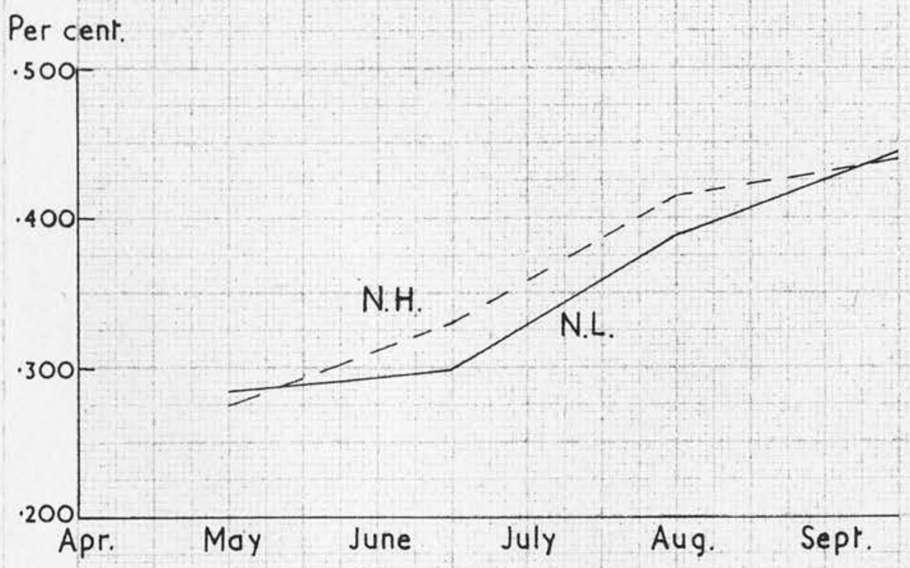
RED CLOVER. Calcium Fig. 22



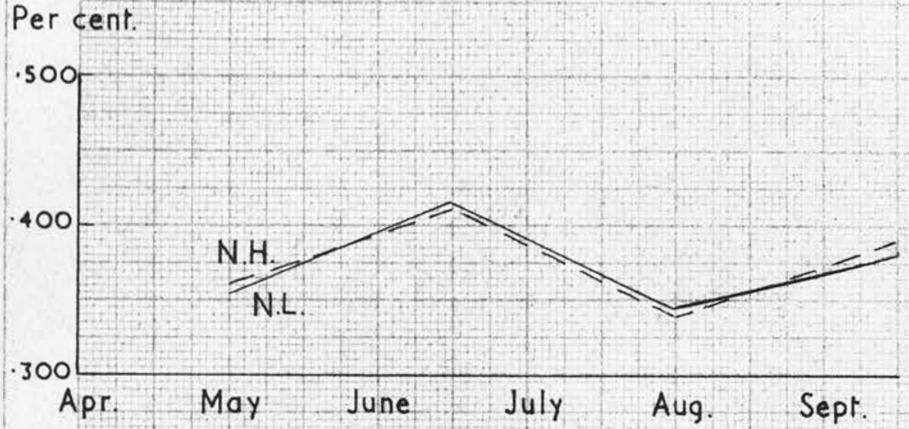
ITALIAN RYEGRASS. Magnesium Fig. 23



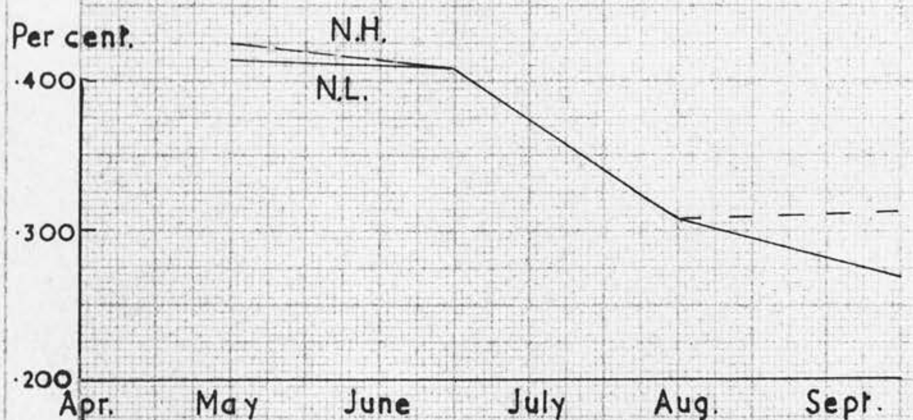
RED CLOVER (I.R.G. plots) Magnesium Fig. 24



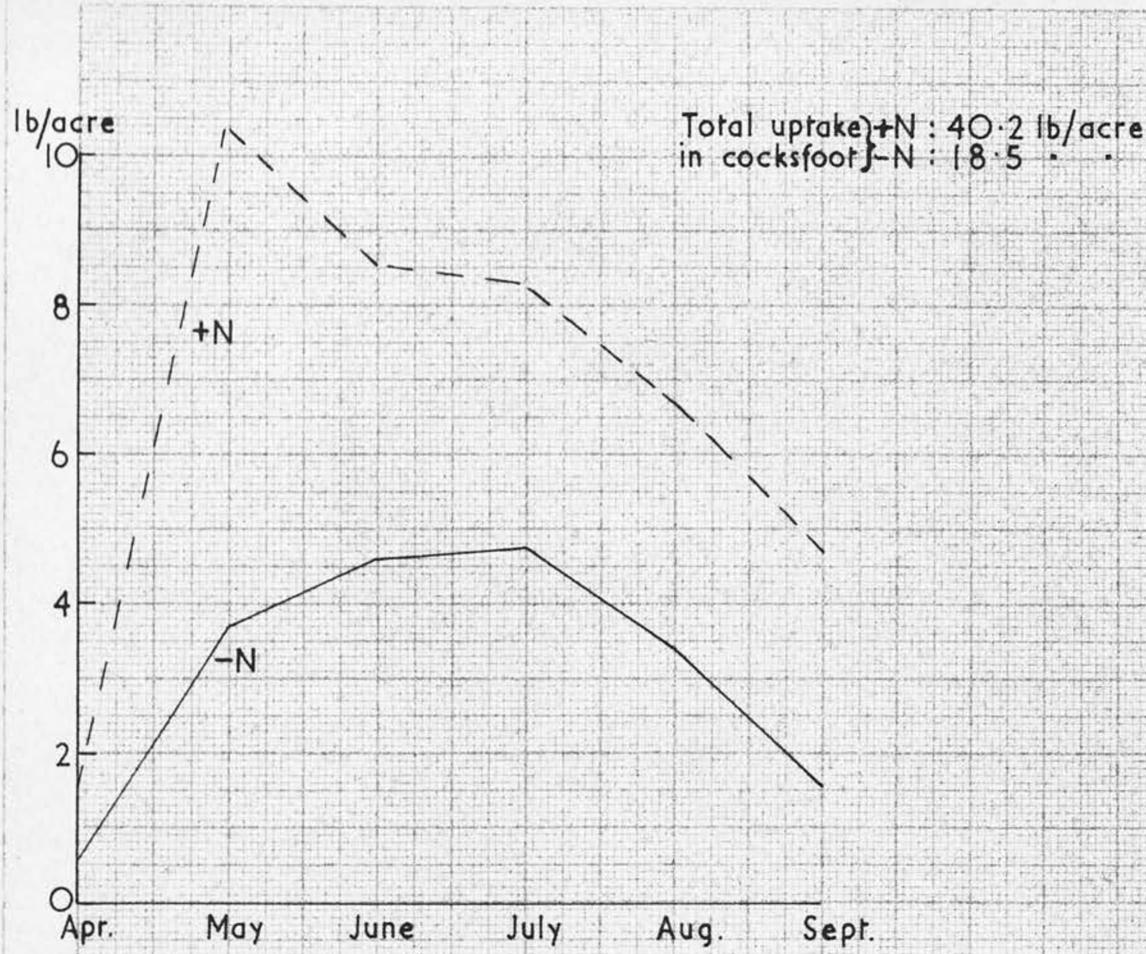
ITALIAN RYEGRASS Phosphorus Fig. 25



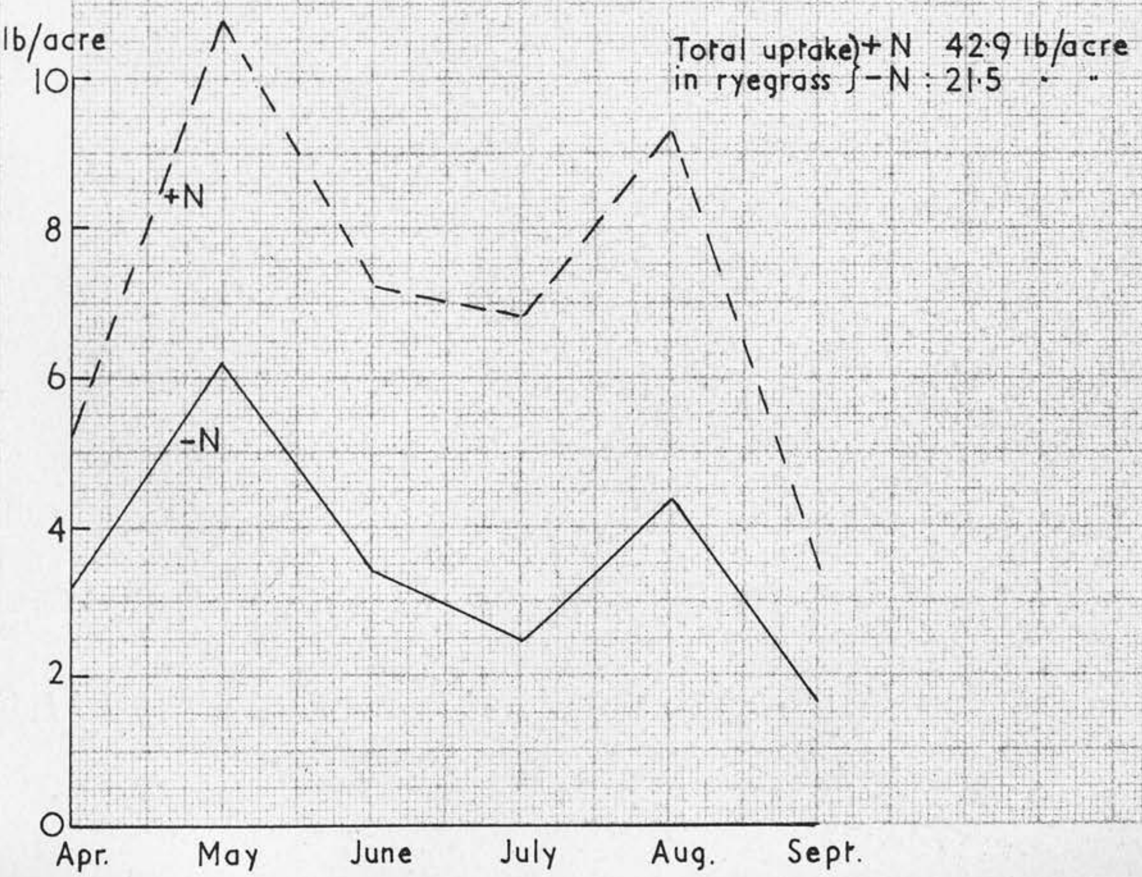
RED CLOVER. Phosphorus. Fig. 26



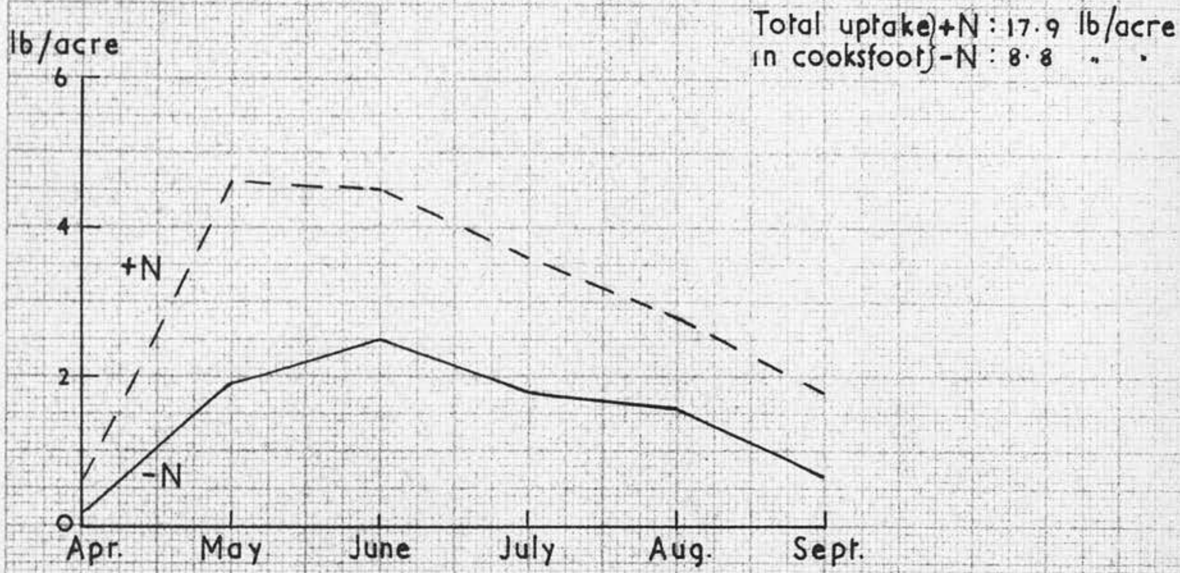
DANISH COCKSFOOT. uptake of calcium Fig. 27



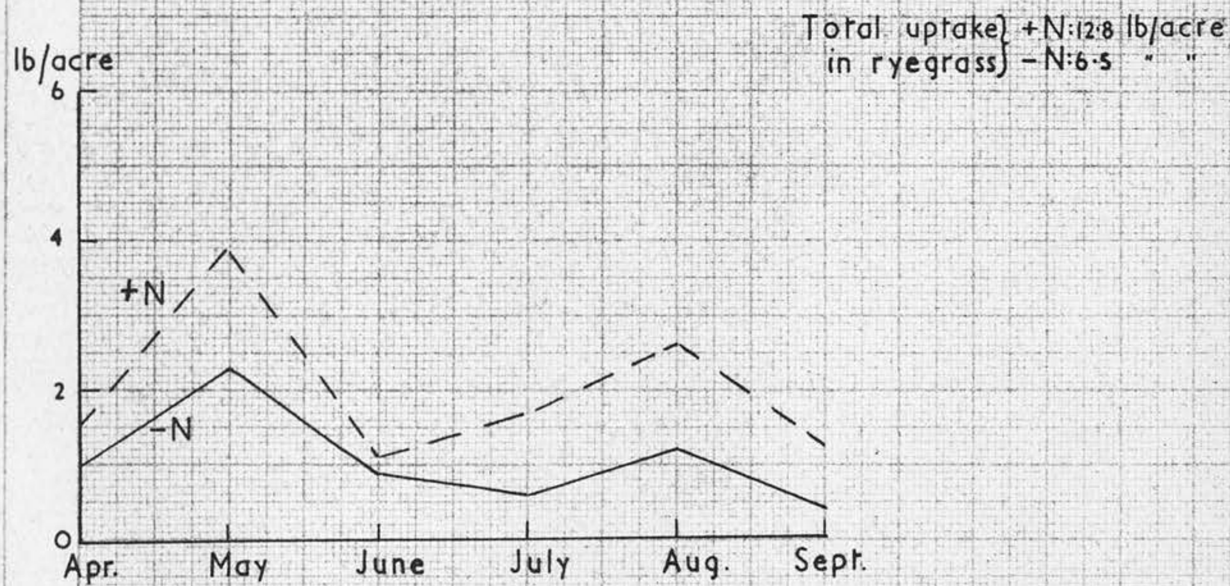
AYRSHIRE RYEGRASS uptake of calcium. Fig.28



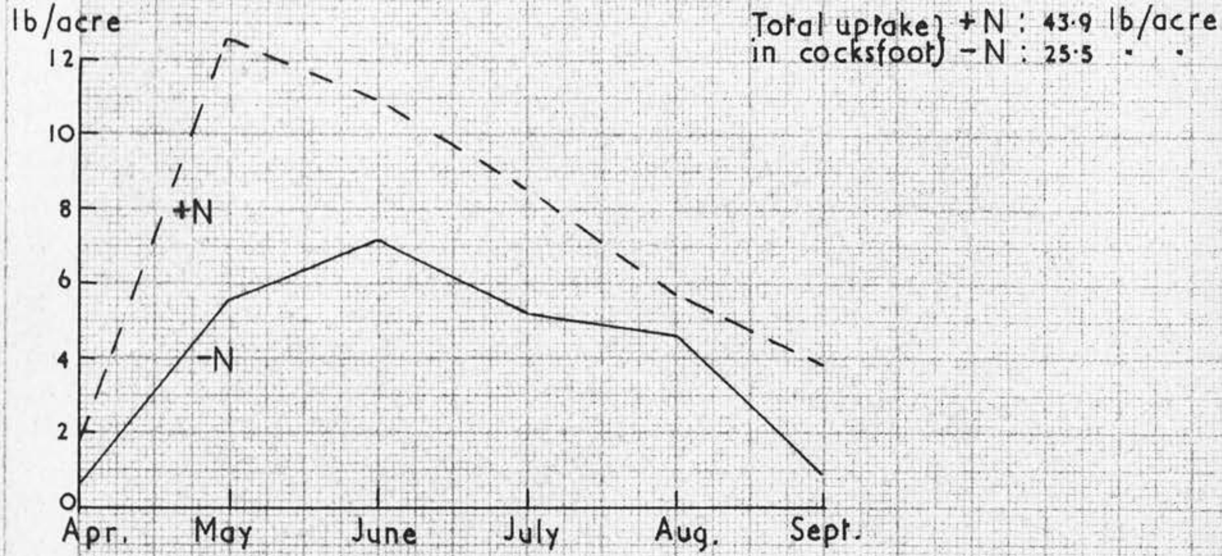
DANISH COCKSFOOT. uptake of magnesium Fig. 29



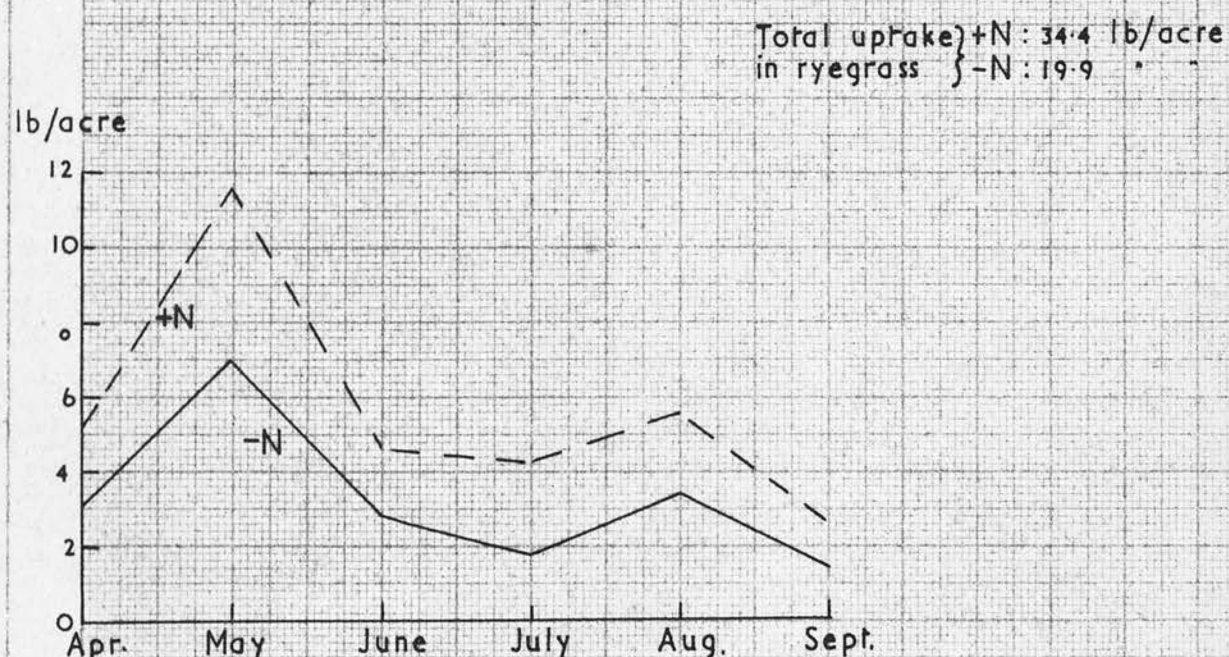
AYRSHIRE RYEGRASS. uptake of magnesium Fig.30



DANISH COCKSFOOT. uptake of Phosphorus. Fig. 31

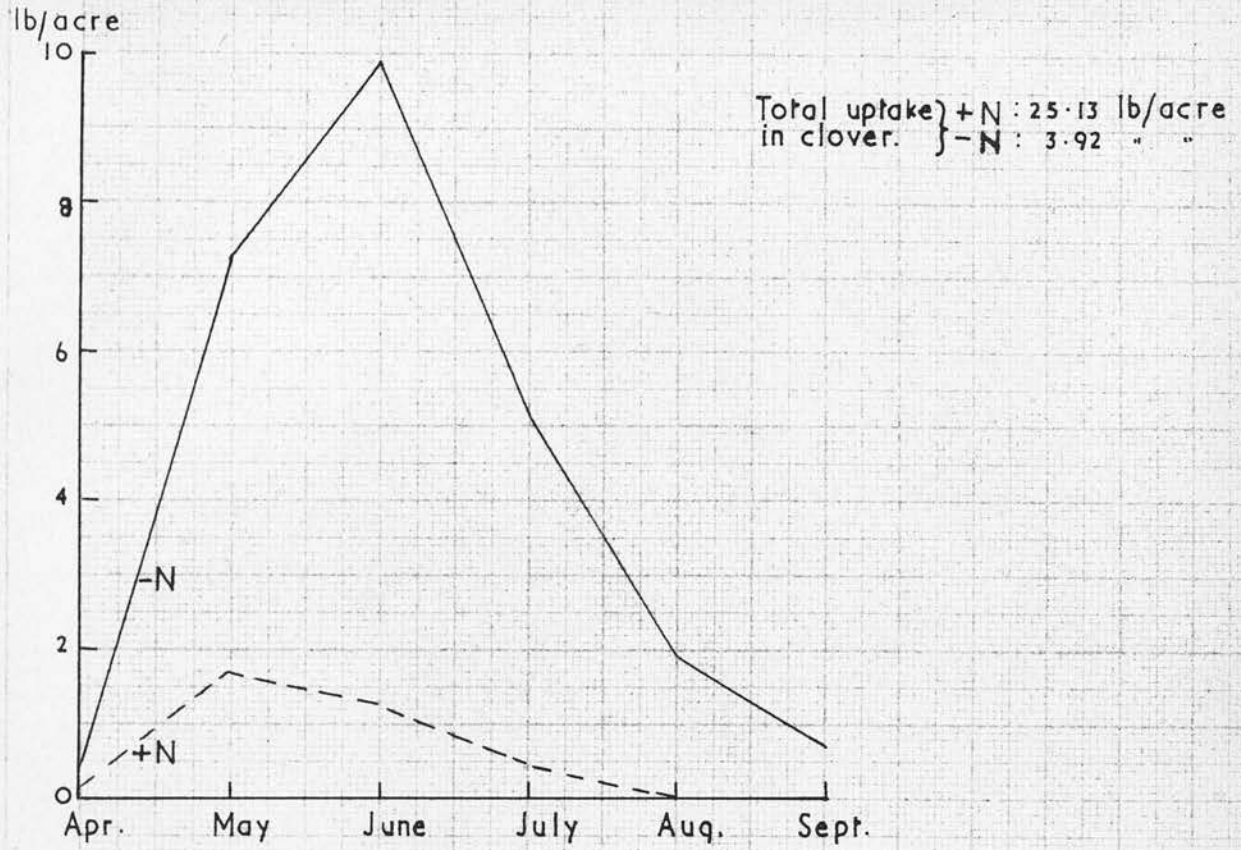


AYRSHIRE RYEGRASS. uptake of Phosphorus Fig. 32



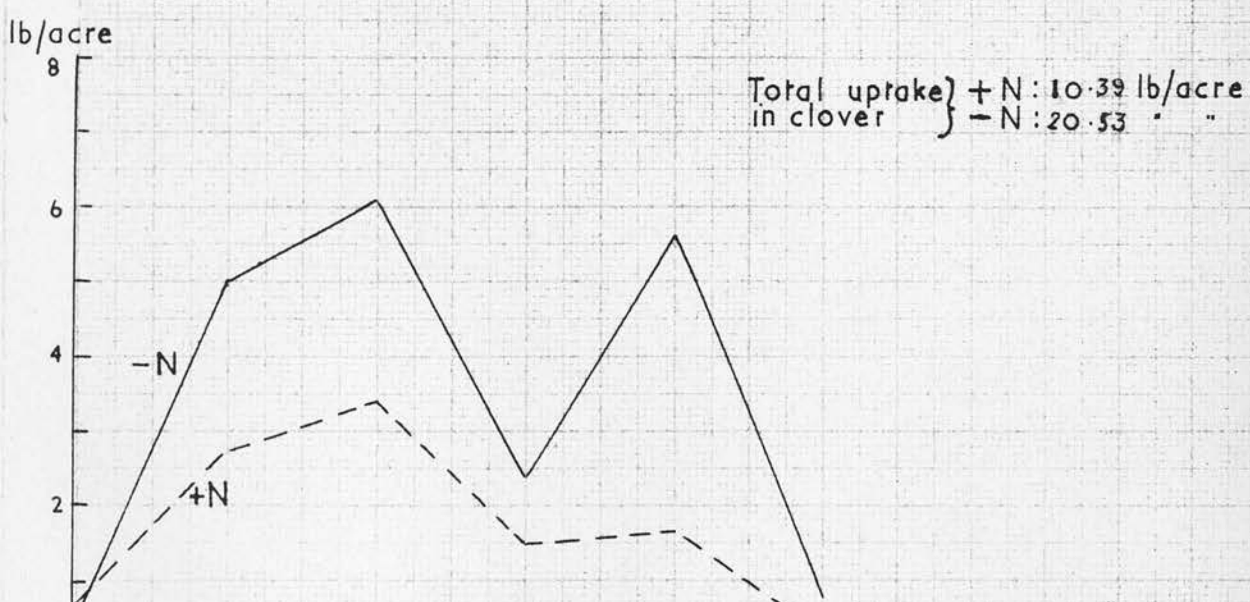
WHITE CLOVER. Calcium (D.C. plots)

Fig. 33



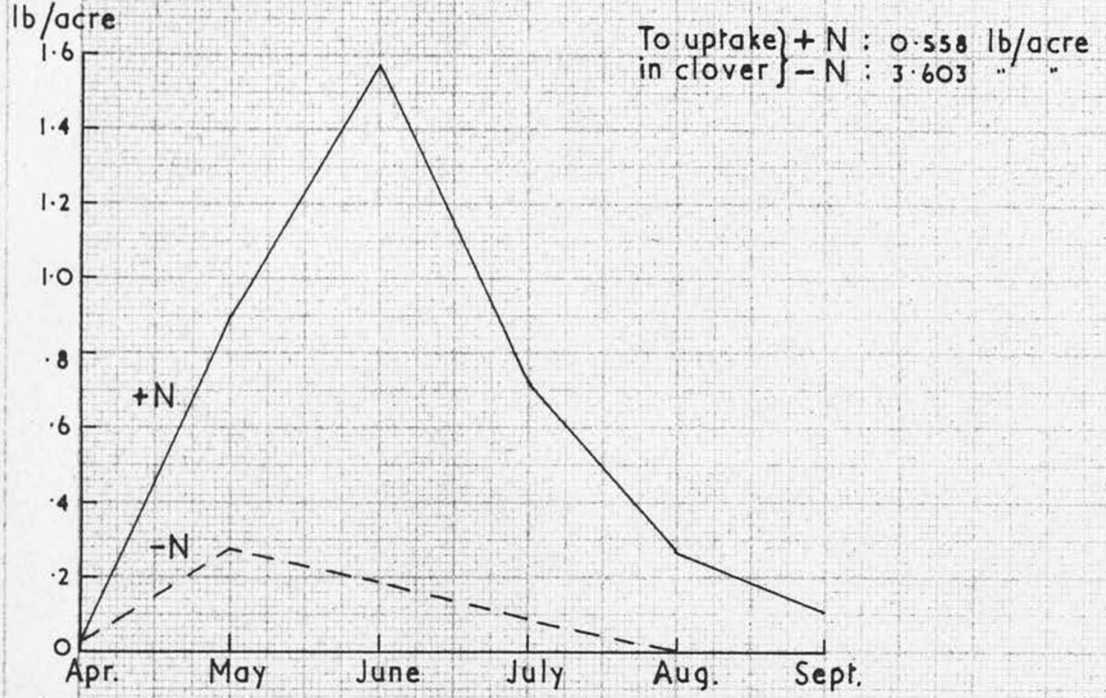
WHITE CLOVER. Calcium. (A.R. plots)

Fig. 34



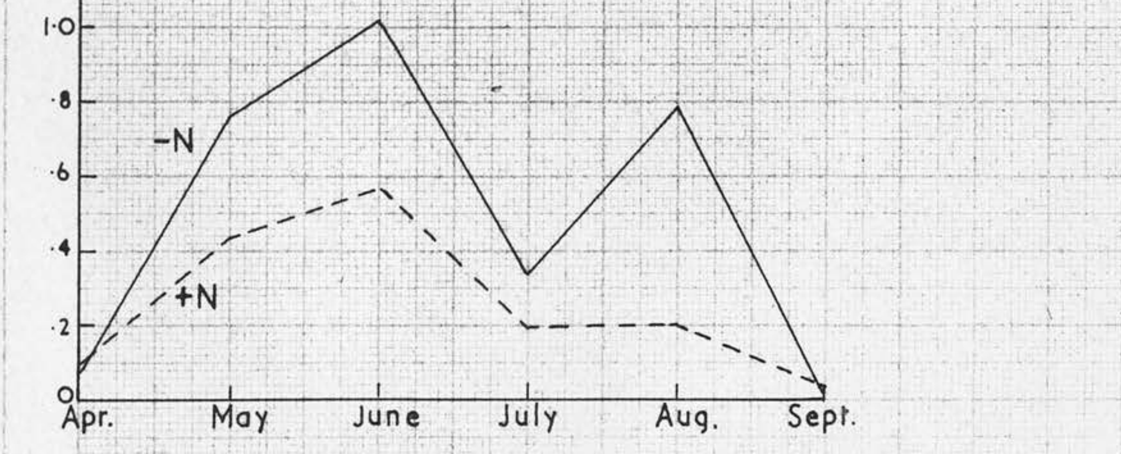
WHITE CLOVER (D.C. Plots) Fig. 35

Uptake of Magnesium.

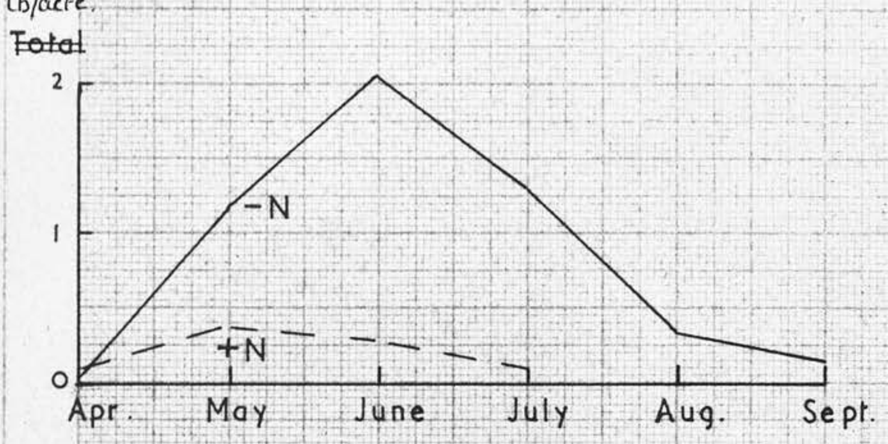


WHITE CLOVER (A.R. Plots) Fig. 36

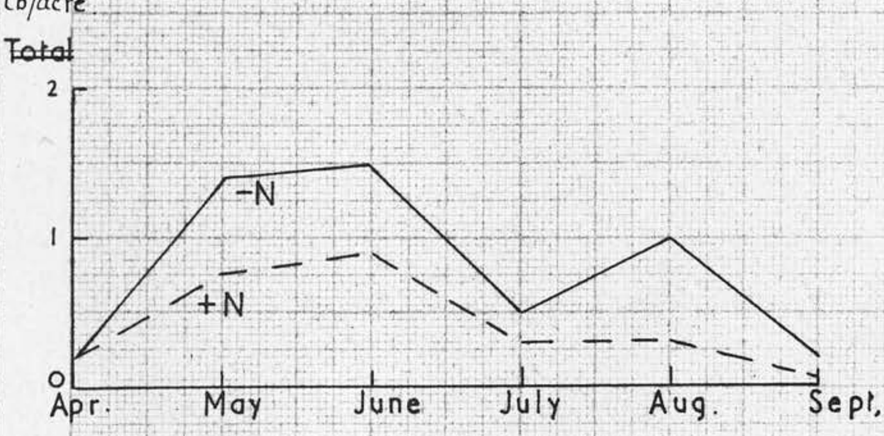
Uptake of Magnesium.



WHITE CLOVER. (D.C. plots) uptake of Phosphorus. Fig. 37

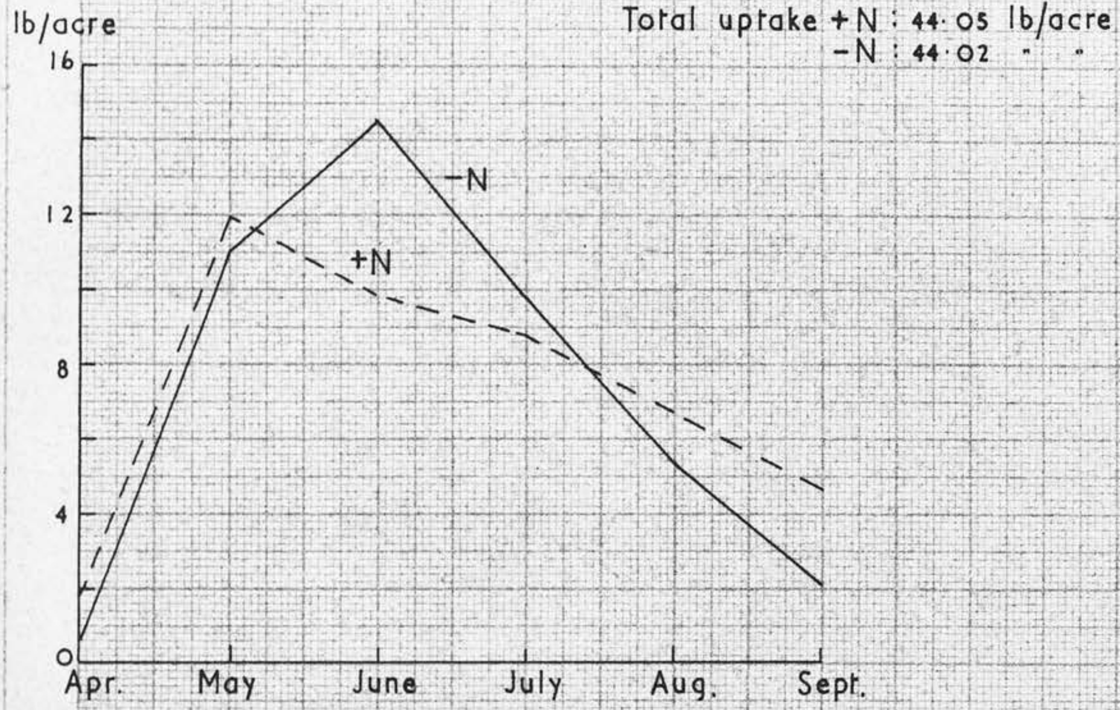


WHITE CLOVER. (A.R. plots) uptake of Phosphorus Fig. 38



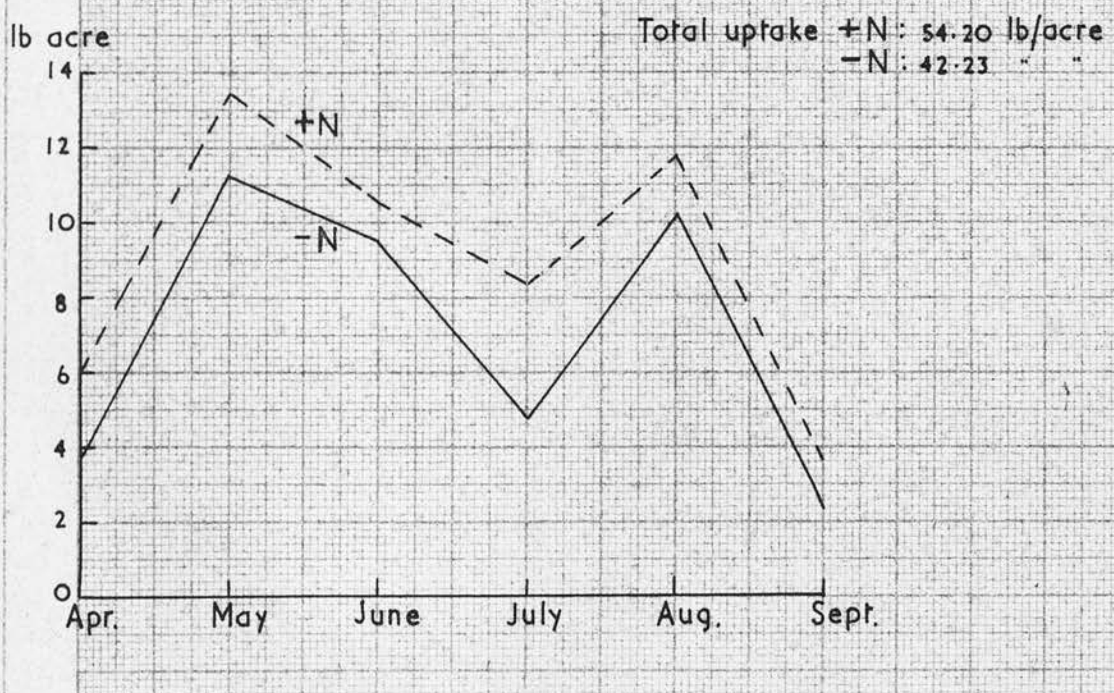
DAINISH COCKSFOOT & WHITE CLOVER Fig. 39

Total uptake of Calcium.



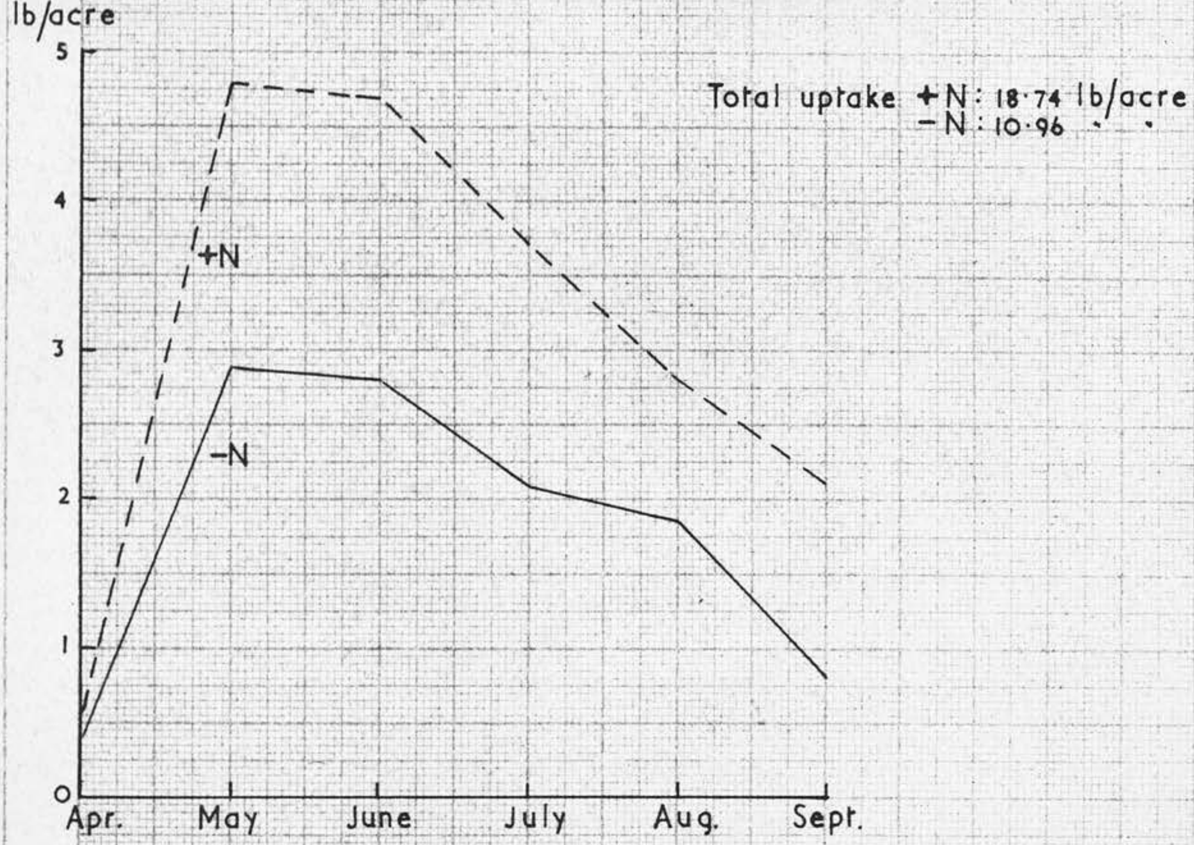
AYRSHIRE RYEGRASS & WHITE CLOVER Fig. 40

Total uptake of Calcium



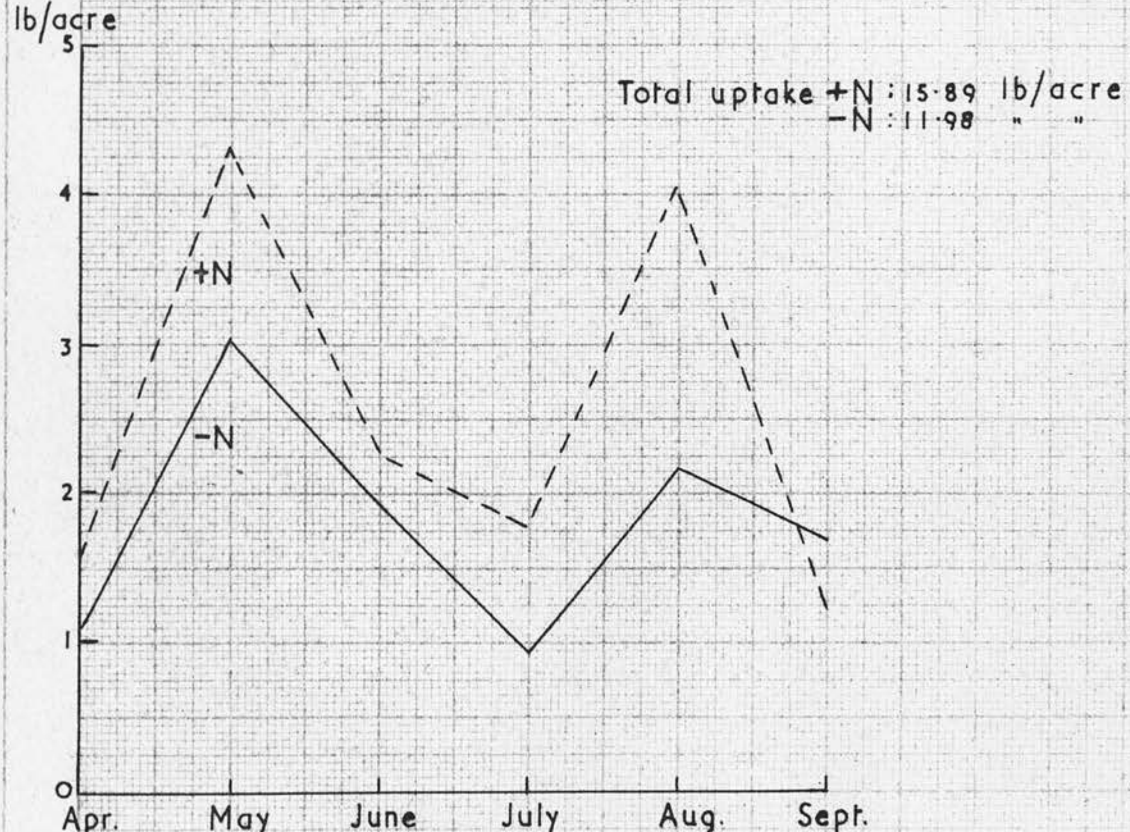
DANISH COCKSFOOT & WHITE CLOVER
Total Uptake of Magnesium

Fig. 41



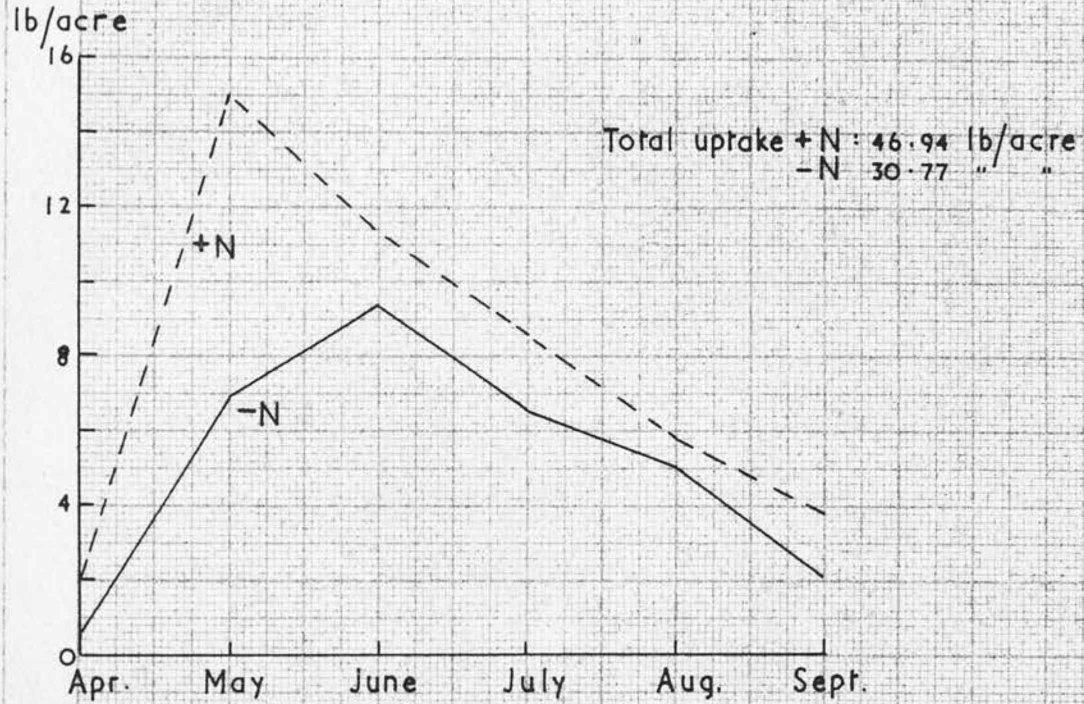
AYRSHIRE RYEGRASS & WHITE CLOVER
Total uptake of Magnesium.

Fig. 42



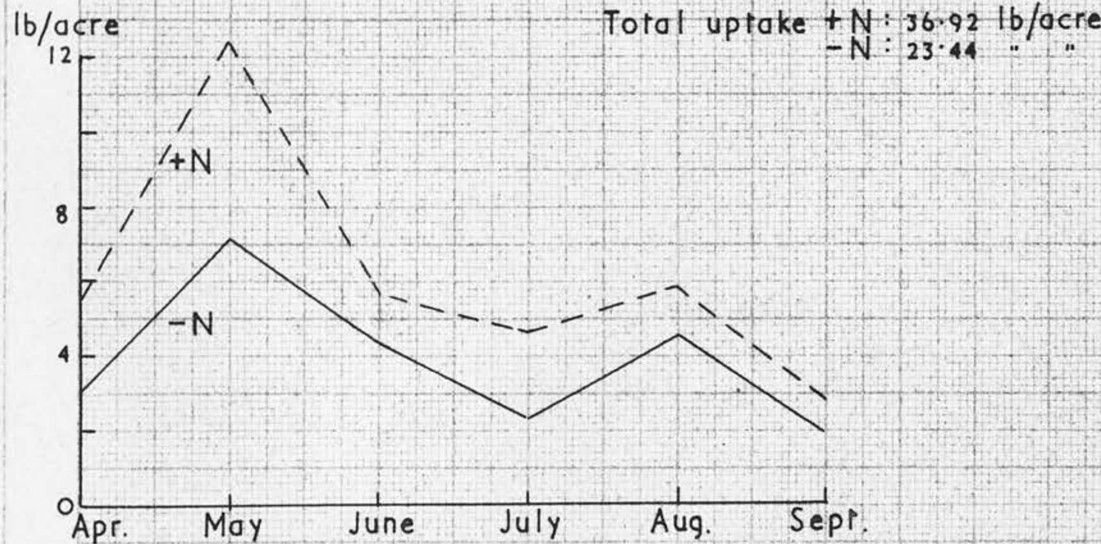
DANISH COCKSFOOT & WHITE CLOVER (D.C. plots) Fig. 43

Total uptake of Phosphorus.

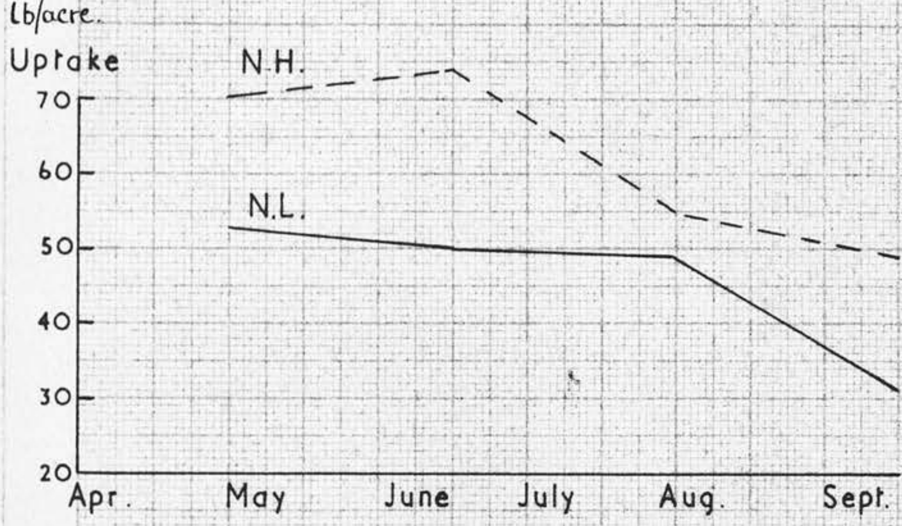


AYRSHIRE RYEGRASS & WHITE CLOVER Fig. 44

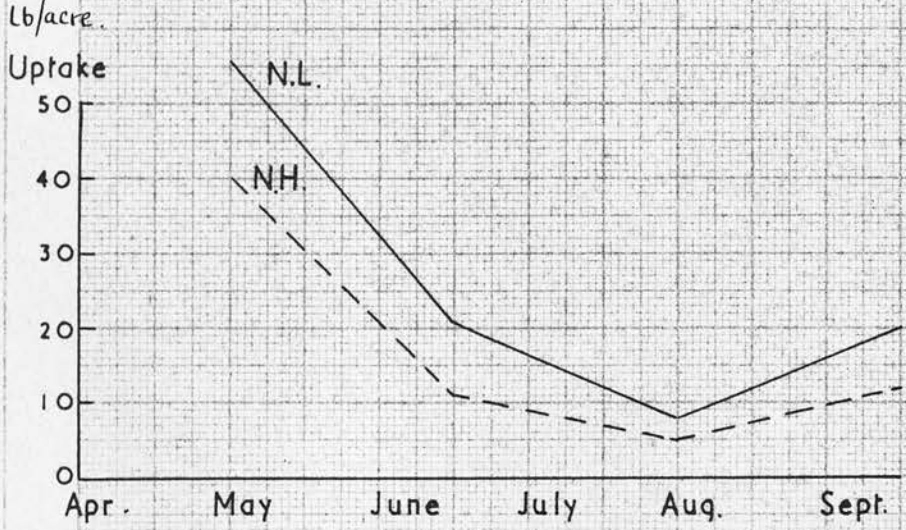
Total uptake of Phosphorus



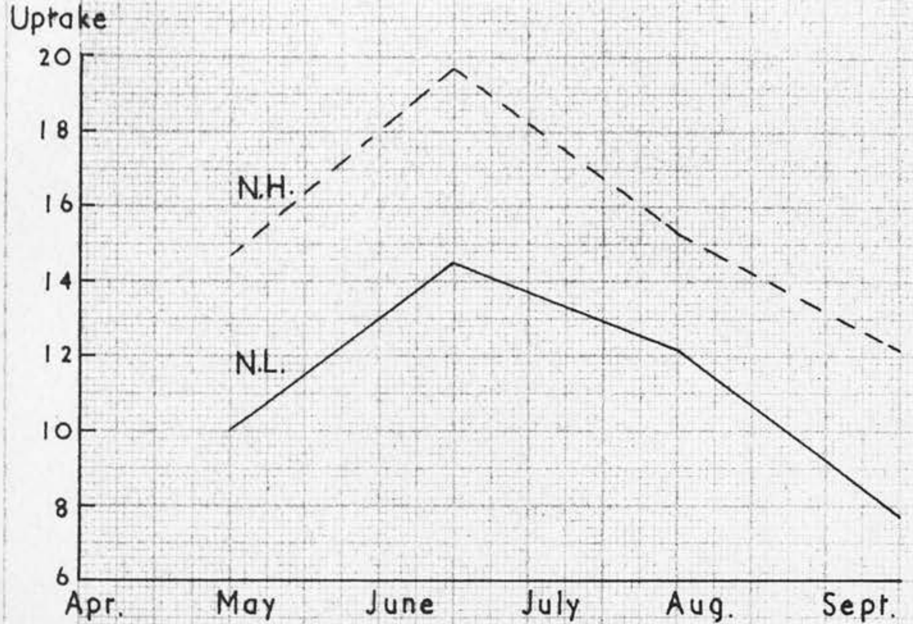
ITALIAN RYEGRASS. Calcium Fig. 45



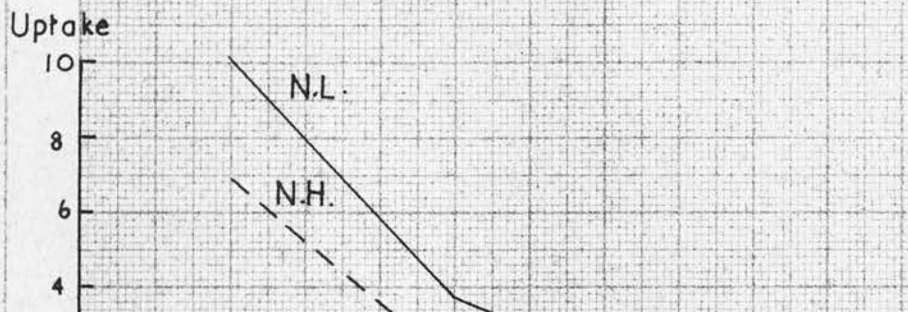
RED CLOVER. Calcium Fig. 46



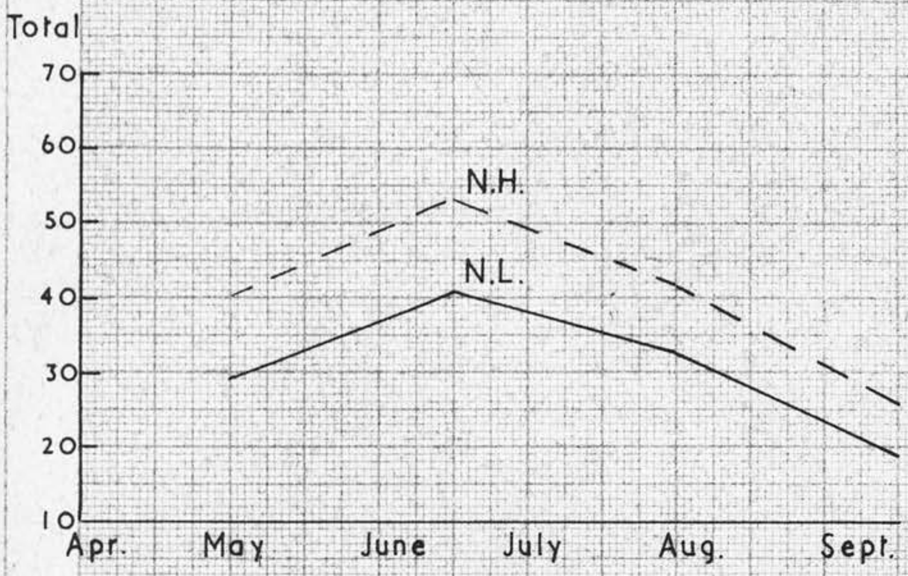
ITALIAN RYEGRASS. Magnesium Fig. 47



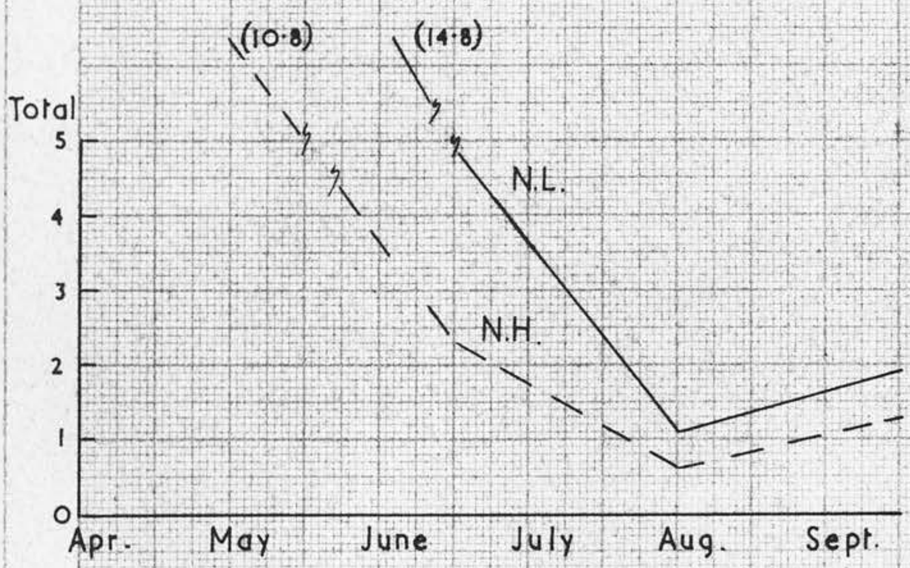
RED CLOVER. Magnesium. Fig. 48



ITALIAN RYEGRASS. uptake of Phosphorus Fig. 49.



RED CLOVER. uptake of Phosphorus Fig. 50



ITALIAN RYEGRASS & RED CLOVER. uptake of Calcium. Fig.51

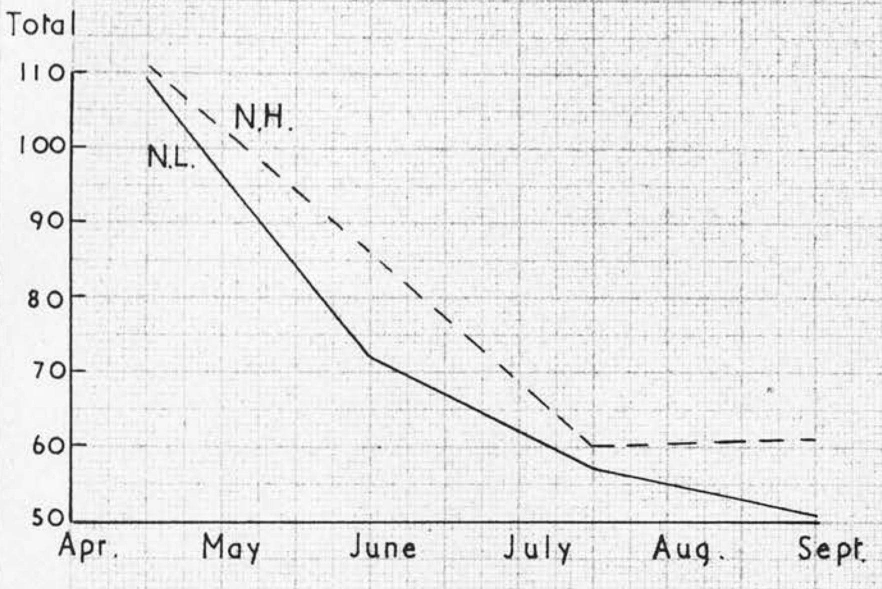


Fig.52
ITALIAN RYEGRASS & RED CLOVER. uptake of Magnesium

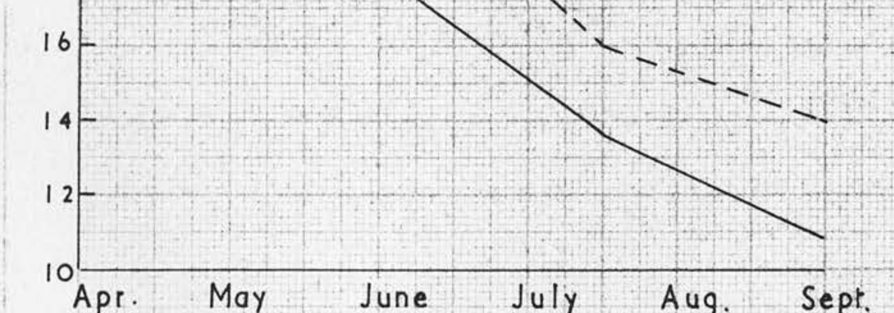
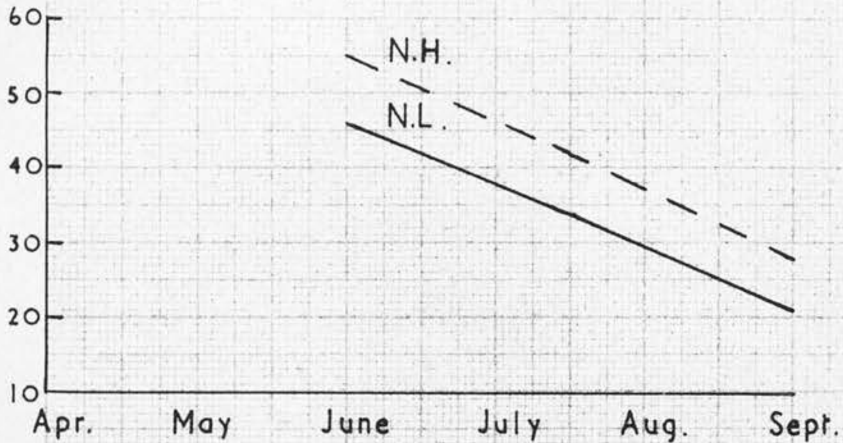
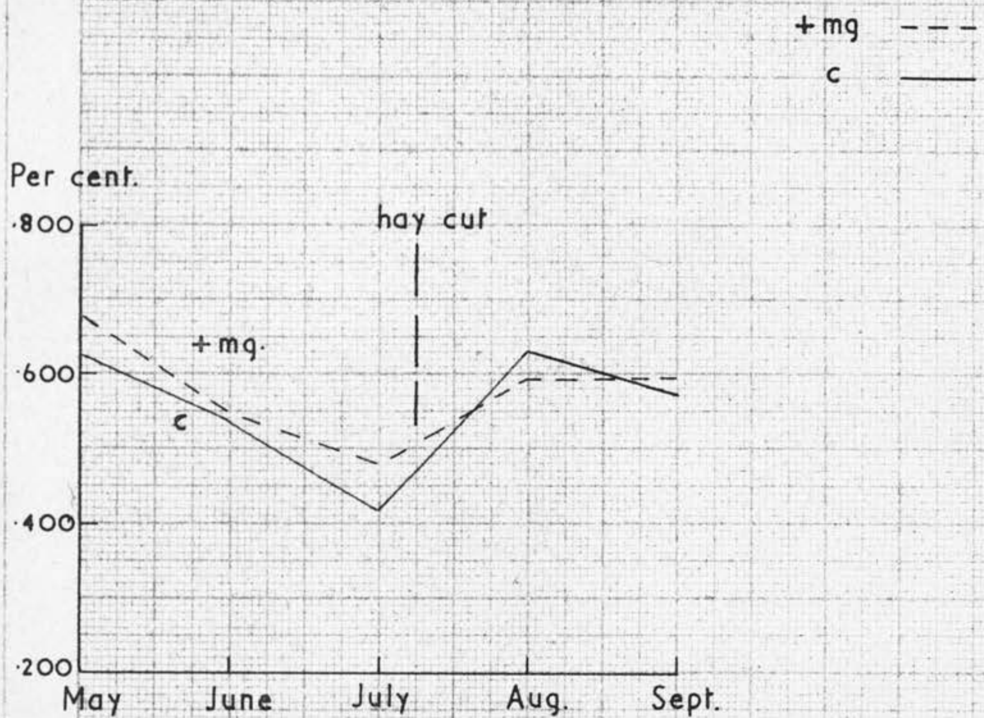


Fig.53

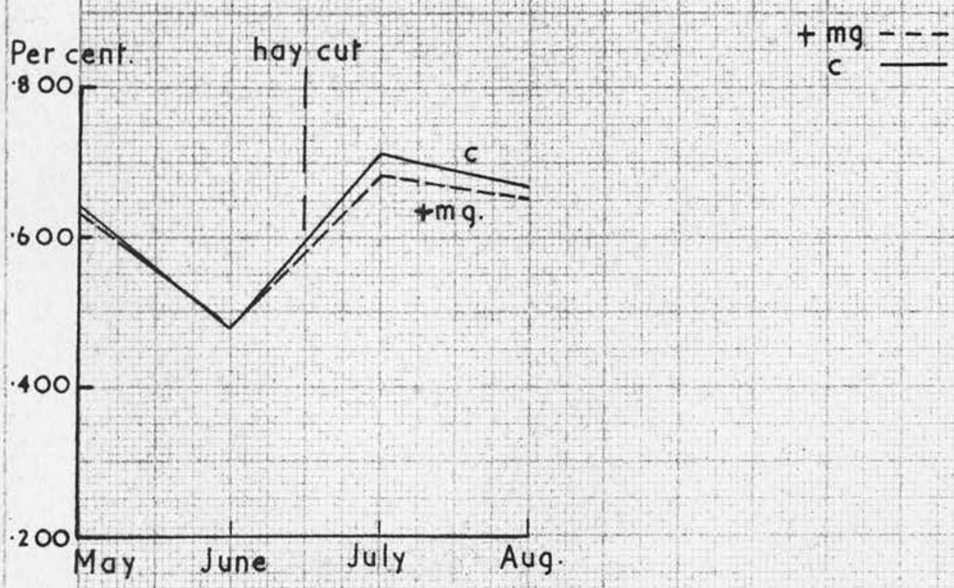
ITALIAN RYEGRASS & RED CLOVER
Total uptake of Phosphorus



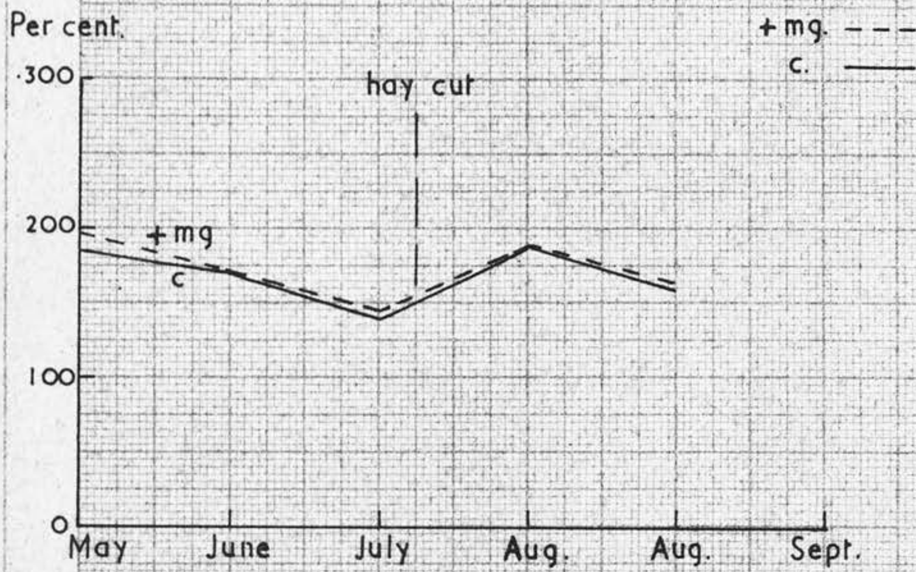
DOWNFIELD SAMPLES Calcium. Fig. 54



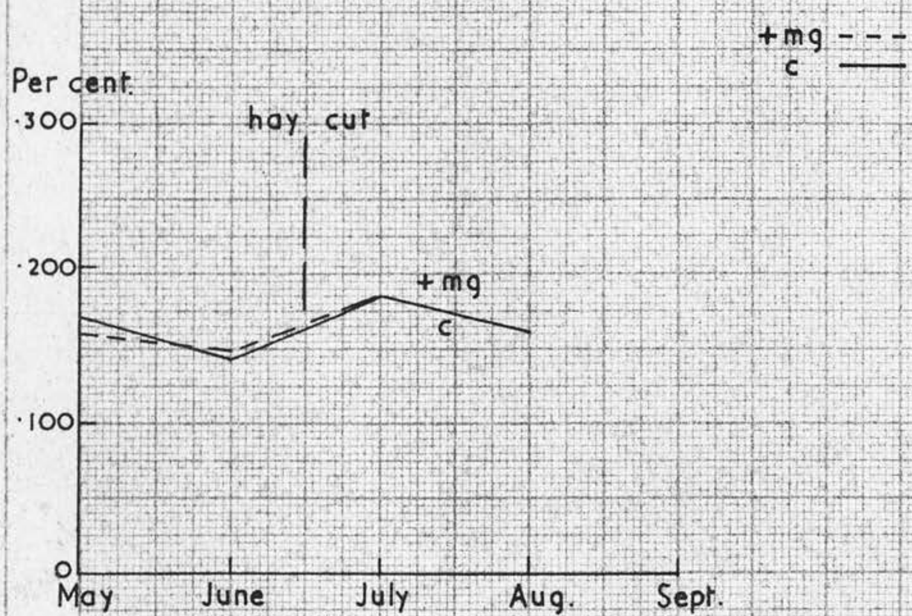
EAST BANK SAMPLES Calcium. Fig. 55



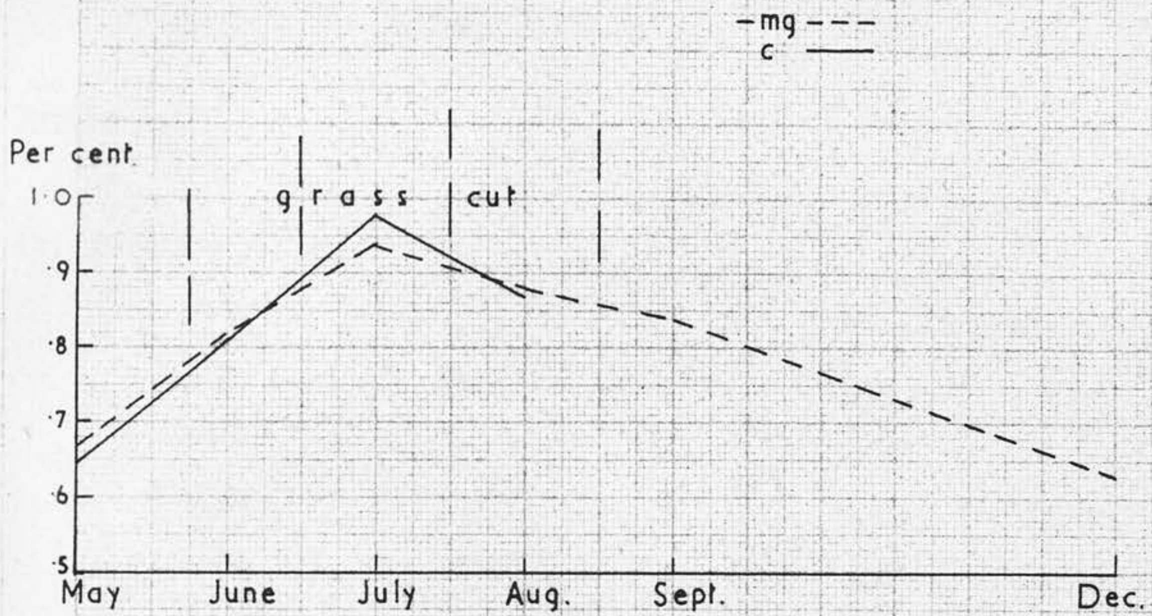
DOWNFIELD SAMPLES. Magnesium Fig. 56



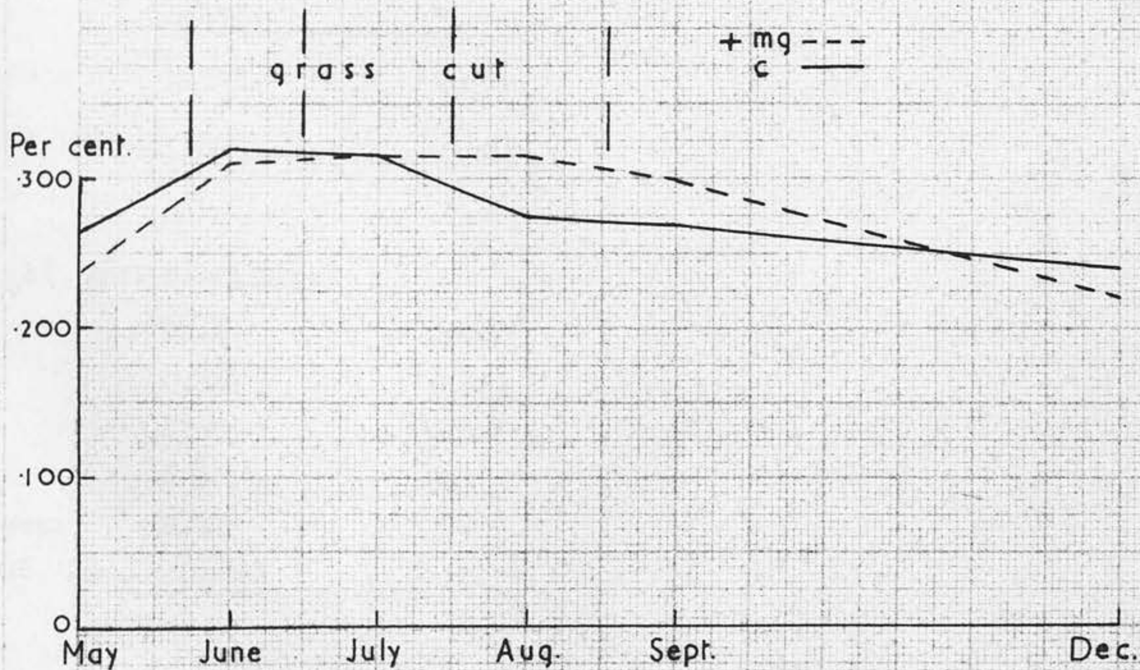
EAST BANK PLOTS. Magnesium Fig. 57



NEW MILL PLOTS. Calcium Fig. 58



NEW MILL SAMPLES. Magnesium Fig. 59



Appendix Table 1.

Errors

(b) Sampling Error

1. Grass from several fields

	% Ca	% Mg
	0.489	0.171
	0.507	0.177
	0.494	0.181
	0.506	0.178
	0.489	0.172
	0.521	0.175
	0.499	0.161
	0.499	0.167
	0.527	0.168
	0.498	0.160
Mean	0.503	0.171
St. Devn.	± .012	± .007

2. Grass from one field

	% Ca	% Mg
	0.523	0.174
	0.537	0.184
	0.542	0.183
	0.535	0.174
Mean	0.534	0.179
St. Devn.	± .007	± .005

(a) Analytical Error

	% Ca	% Mg
	0.502	0.180
	0.503	0.173
	0.503	0.172
Mean	0.503	0.175
St. Devn.	v.small	± .0035

Appendix Table 2.

(b) 3. Recovery of added magnesium.

	I		II	
	% Ca	% Mg	% Ca	% Mg
	0.547	0.228	0.537	0.234
	0.537	0.234	0.529	0.233
	0.535	0.236	0.548	0.237
	0.548	0.230	0.537	0.225
Mean	0.542	0.232	0.539	0.232
St. Devn.	± .006	± .004	± .005	± .004

	2.	I	II
Mean % Mg	0.179	0.232	0.232
Mg added	-	0.050	0.050
Mg recovered		0.053	0.053

(c) Sampling Error.

Grass from 1 field.

	% P	
	0.347	0.344
	0.348	0.344
	0.350	0.344
Mean	0.346	
St. Devn.	± .005	

Appendix Table 3.

(Yield & Mineral content)

BOGHALL SAMPLES : DANISH COCKSFOOT

1953

Cut		D.M. yield lb./acre	% Ash	% Ca	% Mg	% P
1st	-N	119	9.84	0.427	0.161	0.473
	+N	327	11.05	0.472	0.156	0.595
2nd	-N	1171	10.61	0.320	0.166	0.482
	+N	2597	11.45	0.399	0.176	0.487
3rd	-N	1304	13.34	0.353	0.195	0.559
	+N	2263	12.60	0.379	0.199	0.487
4th	-N	1114		0.427	0.166	0.473
	+N	1940	10.62	0.428	0.186	0.442
5th	-N	745	13.85	0.457	0.216	0.637
	+N	1306	11.10	0.511	0.216	0.446
6th	-N	304	13.44	0.488	0.200	0.654
	+N	813	9.00	0.578	0.227	0.478
1954						
2nd	-N	1538	10.46	0.298	0.200	0.431
	+N	2775	10.20	0.291	0.151	0.437
4th	-N	803	11.74	0.475	0.173	0.532
	+N	1741	9.49	0.490	0.181	0.379
6th	-N	549	11.63	0.510	0.191	0.500
	+N	1242	11.08	0.608	0.232	0.445

Appendix Table 4.

(Yield & Mineral content)

BOGHALL SAMPLES

Ayrshire Ryegrass

1953		D.M. Yield lb./acre	% Ash	% Ca	% Mg	% P
1st cut	-N	698	9.37	0.472	0.146	0.441
	+N	1042		0.511	0.145	0.511
2nd cut	-N	1593	9.00	0.392	0.145	0.442
	+N	2322	10.45	0.467	0.169	0.505
3rd cut	-N	481	12.83	0.716	0.195	0.590
	+N	863	12.51	0.831	0.109	0.550
4th cut	-N	397	9.52	0.625	0.155	0.455
	+N	1016	9.61	0.667	0.164	0.428
5th cut	-N	665	10.98	0.665	0.185	0.531
	+N	1305	10.01	0.719	0.203	0.428
6th cut	-N	247	11.94	0.645	0.166	0.635
	+N	485	12.02	0.692	0.250	0.550
1954						
2nd cut	-N	989	10.23	0.389	0.120	0.431
	+N	1711	9.63	0.492	0.151	0.472
4th cut	-N	245	10.53	0.702	0.150	0.475
	+N	841	9.80	0.701	0.091	0.416
6th cut	-N	134	9.96	0.700	0.176	0.440
	+N	350	10.29	0.710	0.182	0.469

Appendix Table 5.

(Yield & Mineral content)

BOGHALL SAMPLES : WHITE CLOVER

1953		D.M. yield lb./acre (with A.R.)	% Ca (with A.R.)	% Mg (with A.R.)	% P (with A.R.)	D.M. yield lb./acre (with D.C.)	% Ca (with D.C.)	% Mg (with D.C.)	% P (with D.C.)
1st cut	-N	35	1.517	0.220	0.504	10	1.617	0.212	0.461
	+N	45	1.532	0.220	0.543	19	1.654	0.184	0.516
2nd "	-N	320	1.573	0.236	0.425	344	2.118	0.262	0.374
	+N	166	1.631	0.256	0.457	97	1.787	0.245	0.450
3rd "	-N	390	1.585	0.263	0.392	532	1.873	0.263	0.398
	+N	204	1.703	0.281	0.430	73	1.800	0.259	0.445
4th "	-N	135	1.770	0.250	0.392	266	1.929	0.273	0.496
	+N	86	1.818	0.231	0.364	31	1.760	0.304	0.438
5th "	-N	300	1.916	0.265	0.341	98	1.959	0.272	0.352
	+N	79	2.153	0.258	0.334	7	2.067	0.296	-
6th "	-N	43	1.565	0.264	0.428	43	1.515	0.251	0.370
	+N	15	1.717	0.246	0.431	2	-	-	-
1954									
2nd cut	-N	31	1.913	0.225		55	1.508	0.227	
	+N	32	1.840	0.209		19	-	-	
4th "	-N	147	1.899	0.217			1.766	0.215	
	+N	53	1.818	0.203			-	-	
6th "	-N	38	1.680	0.228		28	1.696	0.231	
	+N	3	-	-		-	-	-	

Appendix Table 6.

(Yield & Mineral Content)

BOGHALL SAMPLES

Italian Ryegrass

1953	Cut	D.M. yield (lb./acre)	% Ash	% Ca	% Mg	% P
1st	N.L.	8,294	9.58	0.635	0.122	0.355
	H.	11,078	9.50	0.635	0.132	0.363
2nd	N.L.	9,840	9.73	0.512	0.147	0.415
	H.	12,887	9.37	0.578	0.152	0.410
3rd	N.L.	9,715	7.05	0.507	0.126	0.343
	H.	12,532	7.05	0.438	0.122	0.338
4th	N.L.	4,908	9.36	0.630	0.157	0.38
	H.	6,777	8.31	0.724	0.178	0.39

Red Clover		D.M. yield (lb./acre)	% Ca	% Mg	% P
1st	N.L.	3,560	1,586	0.283	0.416
	H.	2,529	1.591	0.273	0.427
2nd	N.L.	1,200	1.790	0.301	0.407
	H.	572	2.049	0.333	0.408
3rd	N.L.	346	2.296	0.389	0.304
	H.	186	2.546	0.415	0.310
4th	N.L.	715	2.746	0.445	0.272
	H.	423	2.808	0.442	0.315

Appendix Table 7.

Variation between plots.

BOGHALL SAMPLES

Danish Cocksfoot (1953)

Cut		% Ash	% Ca	% Mg	% P
5th	-N	14.16	0.481	0.221	0.663
		14.34	0.495	0.231	0.654
		13.41	0.412	0.217	0.617
		13.48	0.430	0.196	0.613
Mean		13.85	0.457	0.216	0.637
St. Devn.			± .020	± .013	± .022
	+N	10.61	0.552	0.220	0.446
		11.62	0.492	0.227	0.446
		10.90	0.524	0.216	0.441
		11.27	0.477	0.202	0.451
Mean		11.10	0.511	0.216	0.446
St. Devn.			± .029	± .009	± .007
Composite					
5th	-N	14.00	0.450	0.204	0.59
	+N	11.04	0.559	0.199	0.43

Ayrshire Ryegrass

1st	-N	8.50	0.484	0.156	0.415
		9.17	0.485	0.145	0.446
		9.57	0.451	0.138	0.464
		9.25	0.467	0.146	0.437
Mean		9.37	0.472	0.146	0.441
St. Devn.			± .014	± .006	± .018
	+N	9.83	0.486	0.127	0.496
		12.38	0.592	0.163	0.496
		10.35	0.475	0.125	0.514
		10.77	0.490	0.163	0.536
Mean		10.83	0.511	0.145	0.511
St. Devn.			± .047	± .019	± .013
Composite					
1st	-N	9.33	0.477	0.134	0.41
	+N	10.25	0.496	0.148	0.48

Appendix Table 8.

Variation between plots.

BOGHALL SAMPLES

White Clover (with D.C.)

Cut		% ash	% Ca	% Mg	% P
5th	-N		1.997	0.274	0.358
			1.929	0.269	0.357
			1.903	0.279	0.346
			2.002	0.264	0.346
Mean			1.959	0.272	0.352
St. Devn.					
	+N	No figures			

White Clover (with A.R.)

Cut		% ash	% Ca	% Mg	% P
1st	-N		1.616	0.205	0.497
			1.492	0.226	0.514
			1.442	0.220	0.508
			1.519	0.227	0.498
Mean			1.517	0.220	0.504
St. Devn.					
1st	+N		1.563	0.205	0.512
			1.495	0.222	0.526
			1.495	0.212	0.576
			1.575	0.241	0.557
Mean			1.532	0.220	0.543
St. Devn.					

Appendix Table 9.

Variation between plots.

BOGHALL SAMPLES

Italian Ryegrass

Cut	Treatment		% Ca	% Mg	% P
2nd	N light	I	0.540	0.151	0.415
		II	0.484	0.143	0.415
	Mean		0.512	0.147	0.415
2nd	N heavy	I	0.580	0.158	0.410
		II	0.575	0.145	0.410
	Mean		0.578	0.152	0.410

Red Clover

Cut	Treatment		% Ca	% Mg	% P
2nd	N light	I	1.820	0.316	0.410
		II	1.759	0.295	0.404
	Mean		1.790	0.301	0.407
2nd	N heavy	I	2.057	0.340	0.404
		II	2.041	0.326	0.414
	Mean		2.049	0.333	0.408

Appendix Table 10.

BOGHALL SAMPLES : Uptake Figures (lb./acre)

Danish Cocksfoot

Cut	Uptake of Ca -N	Uptake of Ca +N	Uptake of Mg -N	Uptake of Mg +N	Uptake of P -N	Uptake of P +N
1953						
1st	0.508	1.543	0.192	0.510	0.563	1.946
2nd	3.747	10.362	1.885	4.571	5.644	12.647
3rd	4.603	8.577	2.543	4.503	7.289	11.021
4th	4.757	8.303	1.849	3.608	5.269	8.575
5th	3.405	6.674	1.609	2.821	4.746	5.825
6th	1.487	4.699	0.733	1.846	1.988	3.886
Sum	18.507	40.158	8.811	17.859	25.500	43.900
1954						
2nd	4.58	8.08	3.08	4.19	6.629	12.127
4th	3.81	8.53	1.39	3.15	4.272	6.598
6th	2.80	7.55	1.05	2.88	2.745	5.527
Sum	11.19	24.16	5.42	10.22	13.66	24.252

Ayrshire Ryegrass

Cut	Uptake of Ca -N	Uptake of Ca +N	Uptake of Mg -N	Uptake of Mg +N	Uptake of P -N	Uptake of P +N
1953						
1st	3.295	5.325	1.019	1.511	3.078	5.325
2nd	6.245	10.844	2.310	3.924	7.041	11.726
3rd	3.444	7.172	0.938	1.104	2.838	4.747
4th	2.481	6.777	0.611	1.666	1.806	4.348
5th	4.422	9.383	1.230	2.649	3.531	5.585
6th	1.593	3.356	0.410	1.231	1.568	2.668
Sum	21.480	42.857	6.518	12.767	19.862	34.399
1954						
2nd	3.847	8.418	1.187	2.584	4.263	8.076
4th	1.720	5.895	0.368	0.765	1.164	3.499
6th	0.938	2.485	0.236	0.637	0.590	1.635
Sum	6.505	16.798	1.791	3.986	6.017	13.210

Appendix Table 11.

BOGHALL SAMPLES : Uptake Figures (lb./acre)

White Clover (with D.C.)

Cut	Uptake of Ca -N	Uptake of Ca +N	Uptake of Mg -N	Uptake of Mg +N	Uptake of P -N	Uptake of P +N
1953						
1st	0.162	0.314	0.0212	0.035	0.0461	0.098
2nd	7.286	1.733	0.901	0.238	1.287	0.437
3rd	9.980	1.331	1.399	0.190	2.117	0.325
4th	5.131	0.546	0.726	0.094	1.319	0.136
5th	1.920	-	0.267	-	0.345	-
6th	0.651	-	0.108	-	0.159	-
Sum	25.13	3.924	3.422	0.557	5.273	0.996
1954						
2nd	0.829	-	0.125	-	-	-
4th	1.943	-	0.237	-	-	-
6th	0.475	-	0.065	-	-	-
Sum	3.247		0.427			

White Clover (with A.R.)

Cut	Uptake of Ca -N	Uptake of Ca +N	Uptake of Mg -N	Uptake of Mg +N	Uptake of P -N	Uptake of P +N
1953						
1st	0.531	0.689	0.077	0.099	0.176	0.244
2nd	5.034	2.707	0.758	0.425	1.360	0.759
3rd	6.182	3.474	1.026	0.573	1.529	0.877
4th	2.365	1.563	0.339	0.199	0.529	0.313
5th	5.748	1.701	0.795	0.204	1.023	0.264
6th	0.673	0.258	0.114	0;037	0.184	0.065
Sum	20.533	10.392	3.109	1.537	3.577	2.522
1954						
2nd	0.593	0.589	0.070	0.067	-	-
4th	2.792	0.964	0.319	0.108	-	-
6th	0.638	-	0.087	-	-	-
Sum	4.023	1.553	0.476	0.175	-	-

Appendix Table 12.

Boghall samples: Total Uptake Figures (lb./acre)

(a) Danish Cocksfoot and White Clover

1953	Uptake of Ca		Uptake of Mg		Uptake of P	
Cut	-N	+N	-N	+N	-N	+N
1st	0.670	1.857	0.404	0.545	0.609	2.044
2nd	11.033	12.095	2.786	4.809	6.931	15.128
3rd	14.583	9.908	2.942	4.694	9.406	11.346
4th	9.888	8.849	2.575	3.702	6.588	8.711
5th	5.325	6.674	1.876	2.821	5.091	5.825
6th	2.138	4.675	0.841	2.184	2.147	3.886
Sum	43.637	44.058	12.424	18.755	30.772	46.940
Ca applied -		282.0				
1954						
2nd	5.409	8.08	3.205	4.19	6.629	12.127
4th	5.753	8.53	1.627	3.15	4.272	6.598
6th	3.273	7.55	1.115	2.88	2.745	5.527
Sum	14.437	24.16	5.947	10.22	13.646	24.252

(b) Ayrshire Ryegrass and White Clover (1953)

Cut	Ca -N	Ca +N	Mg -N	Mg +N	P -N	P +N
1st	3.826	6.014	1.110	1.610	3.254	5.569
2nd	11.279	13.551	3.068	4.349	7.177	12.485
3rd	9.626	10.646	1.974	2.774	4.367	5.624
4th	4.847	8.441	0.950	1.835	2.335	4.661
5th	10.383	11.932	2.165	4.093	4.554	5.849
6th	2.266	3.619	1.707	1.230	1.752	2.733
Sum	42.227	54.203	11.984	15.891	23.439	36.921
Ca applied -		282.0				
1954						
2nd	4.440	9.007	1.257	2.651	4.263	8.076
4th	4.512	6.859	0.687	0.873	1.164	3.499
6th	1.576	2.485	0.323	0.637	0.590	1.635
Sum	10.528	18.351	2.267	4.161	6.017	13.210

Appendix Tables 13 and 14.

BOGHALL SAMPLES: Italian Ryegrass and Red Clover

Ryegrass:	Uptake of Ca		Uptake of Mg		Uptake of P	
1953	N.L.	N.H.	N.L.	N.H.	N.L.	N.H.
1st cut	52.67	70.35	10.12	14.62	39.99	29.44
2nd "	50.38	74.49	14.46	19.59	40.84	52.84
3rd "	49.26	54.89	12.24	15.29	33.32	42.36
4th "	30.92	49.07	7.71	12.06	18.65	26.43
Sum	183.23	248.80	44.53	61.56	132.80	151.07

~~Ca applied~~

Red Clover:	N.L.	N.H.	N.L.	N.H.	N.L.	N.H.
1st Cut	56.46	40.24	10.07	6.90	14.81	10.80
2nd "	21.48	11.72	3.61	1.90	4.88	2.33
3rd "	7.94	4.74	1.35	0.77	1.05	0.58
4th "	19.63	11.88	3.18	1.87	1.94	1.33
Sum	105.51	68.58	18.21	11.44	22.68	15.04

~~Ca applied~~

Total Uptake:	N.L.	N.H.	N.L.	N.H.	N.L.	N.H.
1st Cut	109.13	110.59	20.19	21.52	54.80	40.24
2nd "	71.86	86.21	18.07	21.49	45.72	55.17
3rd "	57.20	59.63	13.59	16.06	34.37	42.94
4th "	50.55	60.95	10.89	13.93	20.59	27.76
Sum	288.74	317.38	62.74	73.00	155.48	166.11

~~Ca applied~~

Appendix Table 15.

Bush Samples

1954		% Ca		% Mg		% P	
Cut grass		-Mg	+Mg	-Mg	+Mg	-Mg	+Mg
1	A*	0.564	0.564	0.152	0.172	0.27	0.29
	B	0.580	0.618	0.133	0.174	0.27	0.27
	C	0.595	0.565	0.160	0.178	0.26	0.25
Mean		0.580	0.582	0.148	0.175	0.27	0.27
2	A	0.512	0.537	0.188	0.208	0.29	0.30
	B	0.559	0.604	0.165	0.167	0.29	0.26
	C	0.477	0.519	0.167	0.178	0.24	0.24
Mean		0.516	0.553	0;173	0.184	0.27	0.27
3	A	0.625	0.507	0.153	0.206	0.29	0.31
	B	0.606	0.602	0.143	0.213	0.31	0.29
	C	0.555	0.515	0.173	0.212	0.28	0.26
Mean		0.595	0.541	0.156	0.210	0.29	0.29
4	A	0.476	0.399	0.162	0.208	0.30	0.32
	B	0.399	0.480	0;158	0.182	0.32	0.30
	C	0.484	0.409	0.167	0.195	0.30	0.31
Mean		0.453	0.429	0.162	0.195	0.31	0.31
5	A	0.320	0.350	0.158	0.205		0.46
	B	0.352	0.324	0.171	0.187	0.45	0.45
	C	0.300	0.290	0.165	0.196	0.41	0.42
Mean		0.324	0.321	0.165	0.196	0.43	0.44

* A : free from B.S.D.

B : control

C : infected with B.S.D.

Appendix Table 16.

Bush Samples

1955		% Ca		% Mg		% P	
Cut grass		-Mg	+Mg	-Mg	+Mg	-Mg	+Mg
1	A	0.613	0.565	0.183	0.211	0.356	0.383
	B	0.571	0.550	0.164	0.208	0.383	0.365
	C	0.549	0.543	0.189	0.212	0.352	0.358
Mean		0.578	0.553	0;179	0.210	0.364	0.369
2	A	0.510	0.524	0.119	0.154	0.226	0.266
	B	0.514	0.462	0.134	0.154	0.271	0.240
	C	0.450	0.411	0.119	0.198	0.227	0.218
Mean		0.491	0.466	0.124	0.170	0.241	0.241
3	A	0.369	0.368	0.129	0.148	0.197	0.202
	B	0.384	0.350	0.135	0.145	0.199	0.179
	C	0.362	0.292	0.120	0.140	0.185	0.188
Mean		0.372	0.337	0.128	0.144	0.194	0.190
4	A	0.317	0.311	0.115	0.144	0.160	0.159
	B	0.334	0.332	0.138	0.157	0.138	0.138
	C	0.268	0.381	0.111	0.133	0.128	0.142
Mean		0.306	0.341	0.121	0.145	0.142	0.146
5	A	0.304	0.266	0.117	0.137	0.121	0.137
	B	0.358	0.318	0.159	0.169	0.097	0.089
	C	0.250	0.258	0.101	0.109	0.088	0.088
Mean		0.304	0.281	0.126	0.138	0.102	0.105

Appendix Table 17.

DOWNFIELD SAMPLES - 1st cut

Treatment	%Ash	% Ca	% Mg	%P
A	11.92	0.515	0.166	0.586
	11.86	0.662	0.178	0.604
	11.74	0.656	0.193	0.617
	11.35	0.627	0.217	0.572
	12.33	0.679	0.179	0.572
Mean	11.84	0.628	0.187	0.590
B	11.72	0.642	0.189	*
	12.25	0.678	0.187	0.595
	11.57	0.689	0.193	0.590
	11.51	0.648	0.221	0.581
	12.04	0.597	0.220	0.586
Mean	11.82	0.651	0.202	0.588
C	11.81	0.578	0.177	0.572
	12.47	0.641	0.173	0.577
	11.82	0.659	0.219	0.595
	11.77	0.572	0.221	0.577
	11.42	0.630	0.251	0.568
Mean	11.86	0.620	0.208	0.578
D	12.17	0.614	0.174	0.663
	12.79	0.644	0.175	0.599
	11.72	0.693	0.146	0.581
	11.10	0.633	0.209	0.578
	11.78	0.609	0.202	0.586
Mean	11.91	0.639	0.181	0.578
E	11.97	0.630	0.190	0.631
	11.58	0.712	0.159	0.563
	11.97	0.720	0.190	0.595
	11.59	0.663	0.239	0.564
	11.87	0.650	0.200	0.586
Mean	11.84	0.675	0.196	0.588

* figure missing.

Appendix Table 18.

DOWNFIELD SAMPLES - 2nd cut : Mineral content.

Treatment	% Ash	% Ca	% Mg	% P
A	9.15	0.667	0.149	0.336
	9.45	0.541	0.153	0.397
	8.78	0.571	0.173	0.387
	9.36	0.501	0.207	0.392
	8.38	0.457	0.156	0.350
Mean	9.02	0.537	0.168	0.372
B	8.97	0.550	0.159	0.352
	9.03	0.536	0.161	0.375
	8.25	0.482	0.150	0.343
	8.52	0.503	0.190	0.364
	9.39	0.471	0.177	0.372
Mean	8.83	0.508	0.167	0.361
C	9.32	0.575	0.164	0.363
	10.11	0.569	0.150	0.345
	9.81	0.530	0.165	0.397
	9.14	0.483	0.184	0.369
	8.84	0.451	0.159	0.355
Mean	9.44	0.522	0.164	0.366
D	9.07	0.588	0.157	0.357
	9.45	0.496	0.159	0.343
	9.03	0.485	0.157	0.350
	8.50	0.483	0.190	0.343
	8.93	0.438	0.158	0.362
Mean	9.00	0.498	0.164	0.351
E	8.68	0.595	0.157	0.332
	8.50	0.542	0.143	0.340
	8.54	0.518	0.192	0.364
	8.26	0.576	0.192	0.346
	8.86	0.500	0.176	0.356
Mean	8.57	0.546	0.172	0.348

Appendix Table 19.

DOWNFIELD SAMPLES - 3rd cut: Mineral content.

Treatment	% Ash	% Ca	% Mg	% P
A	6.72	0.412	0.131	0.236
	6.84	0.406	0.124	0.236
	6.63	0.411	0.131	0.262
	7.08	0.443	0.176	0.279
	6.13	0.442	0.142	0.220
Mean	6.68	0.425	0.141	0.247
B	7.09	0.405	0.116	0.234
	6.41	0.480	0.130	0.233
	6.39	0.444	0.139	0.257
	6.04	0.401	0.155	0.236
	5.99	0.396	0.147	0.231
Mean	6.38	0.425	0.137	0.238
C	8.32	0.441	0.152	0.241
	7.03	0.429	0.165	0.233
	7.47	0.382	0.139	0.257
	6.81	0.459	0.174	0.255
	6.30	0.377	0.139	0.247
Mean	7.19	0.418	0.154	0.247
D	8.85	0.436	0.131	0.271
	7.15	0.422	0.123	0.245
	6.32	0.405	0.120	0.234
	6.62	0.448	0.157	0.247
	6.35	0.416	0.142	0.261
Mean	7.06	0.425	0.135	0.256
E	6.88	0.534	0.128	0.235
	7.32	0.496	0.136	0.251
	6.29	0.472	0.156	0.244
	6.49	0.450	0.163	0.248
	6.35	0.455	0.154	0.224
Mean	6.67	0.481	0.147	0.240

Appendix Table 20.

Forteviot samples: East Bank - **Mineral content.**

	1st cut		2nd cut	
Treatment	% Ca	% Mg	% Ca	% Mg
A	0.659	0.172	0.479	0.146
	0.580	0.173	0.426	0.137
	0.694	0.170	0.498	0.141
	0.693	0.167	0.575	0.157
	0.587	0.157	0.437	0.121
Mean	0.643	0.167	0.483	0.140
B	0.580	0.165	0.497	0.155
	0.625	0.174	0.486	0.135
	0.593	0.154	0.411	0.131
	0.702	0.197	0.472	0.141
	0.540	0.159	0.413	0.126
Mean	0.608	0.170	0.456	0.138
C	0.599	0.172	0.458	0.144
	0.606	0.167	0.431	0.130
	0.588	0.174	0.432	0.143
	0.562	0.175	0.376	0.136
	0.514	0.175	0.350	0.129
Mean	0.574	0.173	0.109	0.136
D	0.603	0.156	0.455	0.138
	0.563	0.154	0.491	0.130
	0.582	0.152	0.435	0.126
	0.580	0.162	0.401	0.139
	0.603	0.157	0.506	0.134
Mean	0.586	0.156	0.458	0.133
E	0.695	0.177	0.517	0.156
	0.592	0.172	0.541	0.151
	0.643	0.181	0.445	0.141
	0.620	0.190	0.473	0.151
	0.577	0.158	0.443	0.129
Mean	0.625	0.176	0.484	0.146

Appendix Table 21.

New Mill samples: 3rd cut.

Treatment	% Ca	% Mg
A	0.980	0.316
	0.943	0.317
	0.854	0.295
	0.923	0.318
	1.017	0.332
Mean	0.943	0.316
B	0.924	0.289
	1.003	0.308
	0.864	0.318
	0.851	0.314
	0.944	0.369
Mean	0.917	0.320
C	1.123	0.298
	0.903	0.319
	0.834	0.295
	0.836	0.305
	0.937	0.334
Mean	0.927	0.310
D	0.815	0.278
	0.934	0.296
	0.928	0.296
	0.823	0.282
	0.966	0.313
Mean	0.893	0.293
E	0.955	0.303
	0.980	0.306
	1.032	0.319
	0.907	0.299
	1.038	0.341
Mean	0.982	0.314

Appendix Table 22 - Turnip Experiments

Downfield Samples: **Yield and Mineral Content**

Roots

Treatment	D.M. yield cwt/acre.	% D.M.	% Ca	% Mg
A	40.62	8.0	0.334	0.1060
	40.76	9.2	0.338	0.0826
	41.44	9.4	0.313	0.0903
Mean	40.94	8.7	0.328	0.0930
B	43.17	9.0	0.287	0.0941
	50.18	9.4	0.350	0.0833
	44.81	8.9	0.294	0.0895
Mean	46.05	9.1	0.310	0.0890
C	43.27	8.9	0.293	0.0942
	44.08	9.4	0.317	0.0861
	46.00	9.9	0.315	0.0933
Mean	44.45	9.4	0.308	0.0912
Mean of 9 results	43.81	9.1	0.315	0.0910

Leaves

Treatment	D.M. yield cwt/acre.	% D.M.	% Ca	% Mg
A	12.72	12.8	1.719	0.198
	12.01	13.9	1.742	0.184
	13.11	12.9	1.840	0.239
Mean	12.61	13.2	1.764	0.207
B	13.44	12.7	1.795	0.211
	10.24	12.8	1.927	0.176
	13.11	12.2	1.903	0.213
Mean	11.50	12.6	1.875	0.200
C	10.15	12.7	1.932	0.211
	11.78	13.3	1.729	0.210
	13.12	13.2	1.769	0.228
Mean	11.68	13.1	1.810	0.216
Mean of 9 results	11.93	13.0	1.816	0.208

Appendix Table 23.

Luthrie samples: **Turnip Experiment - Yield & Mineral content.**

R o o t s

Treatment	D.M. yield cwt/acre	% D.M.	% Ca	% Mg
A	39.55	7.5	0.452	0.124
	47.53	7.8	0.427	0.130
	53.91	8.4	0.411	0.112
Mean	47.00	7.9	0.430	0.122
B	51.33	8.7	0.433	0.119
	40.97	7.1	0.493	0.140
	47.74	8.0	0.375	0.118
Mean	46.68	7.9	0.434	0.126
C8	46.44	7.9	0.445	0.135
	44.04	7.9	0.467	0.126
	53.08	8.5	0.413	0.125
Mean	47.85	8.1	0.442	0.129
Mean of 9 results	47.07	7.966	0.439	0.126

L e a v e s

Treatment	D.M. yield cwt/acre	% D.M.	% Ca	% Mg
A	8.34	13.3	2.224	0.325
	6.41	12.3	2.037	0.371
	5.31	12.9	2.187	0.413
Mean	6.69	12.8	2.149	0.370
B	5.62	13.0	1.982	0.300
	6.86	12.7	2.016	0.334
	4.08	12.6	2.005	0.396
Mean	5.52	12.8	2.001	0.343
C	8.28	13.2	2.001	0.320
	5.90	13.0	2.093	0.335
	4.86	12.5	2.422	0.463
Mean	6.35	13.2	2.174	0.373
Mean of 9 results	**6.19**	**12.9**	**2.108**	**0.362**

Appendix Table 24 -- Turnip Experiment

Downfield & Luthrie samples : Uptake Figures (cwt/acre)

Roots

	Downfield		Luthrie	
Treatment	Ca Uptake	Mg Uptake	Ca Uptake	Mg Uptake
A	13.57	4.306	17.88	4.904
	13.78	3.367	20.30	6.153
	12.97	3.742	22.16	6.038
Mean	13.10	3.805	20.11	5.698
B	12.39	4.062	22.23	6.108
	17.56	4.180	20.20	5.818
	13.17	4.010	17.90	5.633
Mean	14.34	4.084	20.11	5.853
C	12.68	4.076	20.67	6.269
	13.97	3.795	20.57	5.549
	14.49	4.292	21.92	6.635
Mean	13.71	4.054	21.05	6.151
Leaves				
A	21.75	2.519	18.55	2.711
	20.92	2.210	10.82	1.970
	24.12	3.133	14.02	2.647
Mean	22.26	2.621	14.46	2.443
B	24.12	2.836	11.14	1.686
	19.73	1.802	13.83	2.291
	20.57	2.303	8.18	1.616
Mean	21.47	2.314	11.05	1.864
C	19.61	2.142	16.62	2.650
	20.37	2.474	12.35	1.977
	23.21	2.991	11.77	2.250
Mean	21.06	2.536	13.58	2.292

Appendix Table 25

Kale Experiment

FORTEVIOT SAMPLES:

STEMS

Treatment	D.M. Yield	% D.M.	% Ca	% Mg
A	35.10	18.6	0.711	0.180
	35.79	17.5	0.623	0.182
	32.27	17.1	0.884	0.191
Mean	34.39	17.7	0.739	0.184
B	40.04	18.4	0.703	0.188
	37.22	18.2	0.763	0.196
	32.75	16.6	0.868	0.188
Mean	36.67	17.7	0.788	0.191
C	34.23	16.3	0.728	0.181
	41.53	18.6	0.728	0.201
	34.33	17.4	0.818	0.187
Mean	36.70	17.4	0.758	0.190
Mean of Results	35.80	17.6	0.752	0.188

LEAVES

Treatment	D.M. Yield	% D.M.	% Ca	% Mg
A	11.71	14.3	1.373	0.188
	11.11	13.6	1.344	0.185
	10.11	12.5	1.950	0.180
Mean	10.98	13.5	1.556	0.184
B	12.87	13.8	1.323	0.178
	12.27	14.0	1.417	0.183
	10.66	12.6	1.857	0.184
Mean	11.93	13.5	1.532	0.182
C	11.99	13.3	1.158	0.198
	12.35	12.9	1.656	0.191
	11.42	13.5	1.128	0.189
Mean	11.92	13.2	1.314	0.193
Mean of Results	11.61	13.4	1.464	0.186

Appendix Table 26.

FORTEVIOT SAMPLES: Uptake Figures (cwt./acre)

	STEMS		LEAVES	
Treatment	Ca Uptake	Mg Uptake	Ca Uptake	Mg Uptake
A	24.96	6.138	16.08	2.201
	22.30	6.514	14.93	2.055
	28.53	6.164	19.71	1.820
Mean	25.26	6.272	16.91	1.025
B	28.15	7.528	17.03	2.291
	28.40	7.295	17.39	2.245
	28.43	6.157	19.80	1.961
Mean	28.33	6.993	18.07	2.166
C	24.92	6.196	13.88	2.374
	30.23	8.348	20.45	2.359
	28.08	6.420	12.88	2.158
Mean	27.74	6.988	15.74	1.297